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THE

COMBUSTION OF COAL

AND THE

PREVENTION OF SMOKE

CHEMICALLY

AND

PRACTICALLY CONSIDERED.

By C. W. WILLIAMS.

PART THE FIRST.

SECOND EDITION,

ILLUSTRATED WITH COLOURED DIAGRAMS.

LONDON:
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ERRATA.

Page 52, in lines 21, 22, 22, and 29, for "*eight* atoms", read "*four* atoms."

Page 102, for "SECTION VI.", read "SECTION VII."

Page 119, line 4, for "*maximum*", read "*minimum*."

GENTLEMEN,

The following Treatise on the Combustion of Coal is the result of experiments undertaken with the view of advancing the general interests of your establishment, by removing the uncertainties, correcting the errors, and inducing a greater economy, in the important department of the Steam-vessel which relates to the use of Fuel. Should it be productive of any advantage to the City of Dublin Steam-packet Company, my satisfaction will be complete.

I have taken the liberty of addressing this Treatise to you, Gentlemen, as a tribute of respect, and an acknowledgment of the obligations I feel for the confidence you have so long reposed in my zeal and exertions in your service.

I have the honour to be,

Gentlemen,

Your faithful and obedient Servant,

C. W. WILLIAMS.

Liverpool, September 10th, 1840.

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PREFACE

TO THE

SECOND EDITION.

Having drawn attention to the important subject of improving our Furnaces, and the necessity for a closer observation of those chemical conditions on which Combustion is effected, I should, probably, have left the further prosecution of the subject to other and abler hands. The following document will, I trust, justify me in again bringing the subject before the public in a new edition :

" Extract from the Minutes of the Proceedings of the Proprietors of the City of Dublin Steam-packet Company, at the Half-yearly Meeting held in Dublin on the 31st of October, 1840.

" Resolved,—That this Meeting cannot separate without offering to Mr. Williams their sincere thanks for his valuable work on the Combustion of Coal; and that it be recommended to the Directors to request him to superintend the publication of a new edition, at the Company's expense, with the view to its distribution among the Proprietors.

(Signed) " JAMES FERRIER, Chairman.

" P. Howell, Secretary."

For this distinguished mark of approbation, I avail myself of the present opportunity of expressing my acknowledgments; and, for the satisfaction of those who have, in so flattering a manner, added their patronage to this treatise, I have annexed to it the opinions of the following Chemical Professors, whose authority will not be questioned on this subject: viz., Professor Brande, of the Royal Institution, London; Dr. Ure; Dr. Brett, Royal Institution, Liverpool; and Dr. Kane, Royal Dublin Society.

I have carefully revised the work, and have added some illustrations of the mode by which the principles I have dwelt on may be carried into practice.

The diagrams, by which I have endeavoured to illustrate the details of my subject, as regards those definite proportions in which the elements of the several bodies combine, having met the approbation of many chemical authorities of the highest standing, I have endeavoured to improve them, and now present them in, at least, a novel point of view, by being lithographed in colours. The value of this system of *colouring* will be apparent from the facility with which it enables us to appreciate the effect of the relative proportions of each constituent, when considering the union of bodies in masses.

This mode of appealing to the eye, in aid of the memory, will be found the more useful when we consider the importance, and even necessity, of attending to the *volume*, as well as *weight*, of the several bodies with which we have to deal in the process of combustion.

As I lay no claim to chemical authority, and am neither a professed chemist nor a mechanical engineer, but rank merely as a practical observer, I trust this treatise will be received in the spirit in which it has been undertaken, namely, as an effort to induce mechanical engineers, and those who are interested in the use of fuel in the several departments of the arts and manufactures, to refer more to the chemical conditions on which alone combustion can be effected, and the direction in which they should seek for the true principles on which their furnaces may be improved.

Liverpool, March 1, 1841.

PREFACE.

It may be asked, why I should have undertaken to write a treatise on a branch of chemistry; or why suppose I could say any thing on the subject of combustion which had not already been better said by many competent chemical professors.

The reply to the latter question must be sought in the following pages. My reply to the former is a short statement of facts, which, I trust, will exonerate me from presumption, on the one hand, or any uncalled for interference, on the other.

Being much interested in the improvement of steam-vessels, from my connexion with several steam navigation companies, and having had a longer and more extended experience in the details of their building and equipping than, perhaps, any individual director of a steam company in the kingdom, my attention has been uninterruptedly given to the subject since the year 1823, when I first established a steam company, and undertook to have the first steam-vessel constructed capable of maintaining a commercial intercourse across the Irish Channel, during the *winter* months, and which, till then, had been considered impracticable.

Since that time to the present, my object has been the imparting, through the instrumentality of the most experienced ship-builders and steam-engine manufacturers, the greatest practicable degree of perfection and efficiency to every part of the hulls and machinery of steam-vessels.

With respect to the improved state to which the *hulls* of steam-vessels have been brought, I refer to the papers and detailed specification for the building of the last of those belonging to the City of Dublin Steam Company, as furnished by myself and Mr. J. C. Shaw, the Marine Manager of that Company, to the Commissioners of Steam-vessels Inquiry, Josiah Parkes, Esq., Civil-engineer, and Captain Pringle, and printed in the Appendix to their Report.

For a practical illustration of the perfection to which both *hulls* and *machinery* have been brought, I refer to the steamship " Oriental," one of those now under contract with her Majesty's Government for conveying the East India Mails between Great Britain and Alexandria.*

The result of this long experience is the finding, that, notwithstanding the improved state to which the construction and appointments of the hull and general machinery of steam-vessels have arrived, great uncertainty and risk of failure still prevail in the department of the *boiler*, as regards the *use of fuel* and the *generation of steam.*

Much, certainly, has been done towards imparting strength to the boiler and lessening the risk of explosion. The most experienced engineers are, however, still unable to decide, *previously to trial*, either as to the quantity of fuel that will be consumed or of steam to be generated.

It is true, the engineer, who undertakes the construction of the engines, also undertakes that the boilers shall provide a sufficiency of steam to work them ; but what that *sufficiency* means, has not been decided ; and, in too many instances, the absence of some fixed data on the subject leads to complaints and references, which, though they may end the disputes between the owners and makers of the engines, leave the evils of a deficiency of steam or a great expenditure of fuel unabated.

---

* The hull of the " Oriental" was built by Messrs. Thomas Wilson and Co., and the machinery constructed by Messrs. Fawcett and Preston, of Liverpool.

If there happen to be "*steam enough*," the engineer's triumph is complete; although it is seldom that an account is taken of the quantity of fuel consumed, or whether it be attended with economy or waste. If with economy, the merit of the engineer is enhanced; but, if with waste, the sufferers, having no redress, keep their grievances to themselves, and the leger account of fuel consumed is the only index to the cause of that absence of profit which is too often the usual result.

So long as this uncertainty prevailed, and the consequences of failure were so serious, steam-ship owners were naturally cautious in interfering; although it was manifest, from the constant changes in the proportions and other details in the construction of their boilers, that the engineers themselves were without any fixed principles to guide them. So long as the operations of steam-vessels were confined to coasting or short voyages, the consequences of these defects in boilers, as regards the quantity of fuel, was a mere question of pounds, shillings, and pence. When, however, those operations came to be extended to long-sea voyages, these consequences took a more comprehensive range, and involved the more important question, whether such voyages *were practicable* or otherwise.

Under the conviction of the danger of taking responsibility from the engineer, although alive to the prevailing uncertainty and risk, I felt, in common with other directors of steam companies, an unwillingness to interfere. From being so deeply interested in the improvement of this department of steam navigation, I have watched, with no small anxiety, the efforts of the engineers to arrive at some degree of certainty in what was admitted, on all hands, to be the most serious drawback to the successful application of steam-vessels to long-sea voyages. I perceived the absence of any intelligible or well-founded principle in the construction of the boiler;—that the part on which most depended appeared least understood, and least attended to, namely, the *furnace;* and that this was too often left to the skill (or want of it) of working boiler-makers or bricklayers.* I saw that, although the great operations of combustion carried on in the furnace, with all that belongs to the introduction and employment of atmospheric air, were among the most difficult processes within the range of chemistry, the absence of sound scientific principles still continued to prevail; yet on these must depend the extent or perfection of the combustion in our furnaces.

Years were still passing away, and, while every other department was fast approaching to perfection, all that belonged to the combustion of fuel—the production of smoke—and the wear and tear of the furnace part of the boiler, remained in the same *status quo* of uncertainty and insufficiency; and, although the recourse to new plans and new smoke-burning expedients continued, and every year brought forth a new batch of infallible remedies for "consuming smoke and economizing fuel," success and certainty seemed as unattainable as ever, notwithstanding the abundance of labourers in the field of speculation and invention.

In fact, things seemed almost retrograding into greater doubt and want of system, rather than advancing to perfection, or even keeping pace with the improvements of the hulls and engines; and many of the furnaces, both of marine and land boilers, constructed within the last few years, with the absence of any arrangement for effecting a perfect or economical use of fuel, exhibit greater violations of chemical truths, and a greater departure from the principles on which nature proceeds, than any preceding ones which have come under my observation.

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* In a late treatise on "Steam Boilers," by Robert Armstrong, of Manchester, the author actually speaks of chemistry and its connexion with the subject of the combustion of fuel with the degree of contempt which, to say the least, is discreditable to this age of mechanics' institutions; and gives a preference, with no small degree of triumph and self-complacency, to the working bricklayer, rather than to the "theories" of Davy or Dalton!

With respect to the all-important considerations, the quantity of fuel required, or the most judicious mode of effecting its combustion, the problem,—whether the boiler (for the furnace is never spoken of apart from the boiler) would generate more or less steam; produce more or less smoke; or consume more or less fuel,—still remained to be decided by the *argumentum ad rem* alone,—*experiment;* when, if unsuccessful, the evil would be irremediable, and the owners doomed to eat the bread of disappointment, if not of loss. The result of a boiler, on being tried, turning up a trump, and giving "plenty of steam," with a small consumption of fuel, was, indeed, tantamount to a profitable employment of the vessel; while the reverse was inevitably attended with a succession of alterations, and, most likely, of loss to the speculation.

Practically speaking, then, the managers of steam companies ask, "Where are they to begin? where look for a remedy for these too often overwhelming evils? Are they to remain in doubt for ever?" The interests of steam navigation companies and steam-engine manufacturers are alike concerned in the inquiry; while the profit, if not the practicability, of effecting *long-sea* voyages is actually dependant on this very point, the economizing fuel by effecting its more perfect combustion.

These were the considerations which operated with me when adding my mite to the inquiry; an inquiry which, it is manifest, will not be originated by the "working boilermaker or bricklayer"; and, if I have not perfected the system which so loudly calls for improvement, I have, at least, directed the inquirer into the right road.

On my own part, the reluctance to interfere and share the risk of failure was put an end to by an *imperious necessity.* I was brought to the conclusion, that, to remain any longer a mere spectator of those abortive efforts towards improvement, and, in all cases, to wait the result of *trial*, before it could be ascertained whether a new boiler was to turn out good or bad, wasteful or economic, was inconsistent, if not with the progress of steam navigation, at least with the most vital interests of those for whom I was acting.

This *ultima ratio* for interference, *necessity*, became also the more urgent, since long-sea voyages have been contemplated. The determination to examine for myself and exercise my own judgment was forced upon me by the failure of the steam-ship the "Liverpool," on her first voyage to New York.* I saw, that the owners and managers of steam companies could be in no worse position (as to risk or responsibility, touching the boiler department) from their *interference*, than that in which they were placed under the circumstances of *non-interference.*

---

* The errors of the engineers and others, which led to the failure of the first voyage of the "Liverpool," were erroneously and unworthily attributed to Mr. Shaw, Marine Manager of the Dublin Steam Company. The details hereafter to be given will show, that whatever interference took place on his part was dictated by sound judgment and experience, and tended to *relieve*, if it could not *remove*, the original errors in the construction of the furnaces and boilers of that vessel. The circumstances connected with this vessel furnish an additional motive for interference on the part of the managers and directors of steam companies; for here was a practical illustration of the fact, that, not only may the owners of steam-vessels be doomed to suffer, in a pecuniary point of view, the consequences of the errors of engineers, but, possibly, be subjected to censure, and even calumny, from the efforts of others to throw the onus of public disappointment from their own shoulders.

I cannot allow this opportunity to pass without noticing the unwearied efforts towards effecting improvement, and the knowledge of all the details of the steam-vessel and its machinery, which have, during fifteen years, been brought to bear on this subject by Mr. Shaw, with whom much of those details of practical improvement originated, and which are now exhibited in the "Oriental," steam-ship.

In the proper place I will show, that, of late years, as much uncertainty as to the success of a new boiler has prevailed as when I first began operations, eighteen years ago; and that few boilers, for land or marine engines, even from well-established houses, exhibit more in the way of effecting perfect combustion or economy of fuel than those of any former period since the days of Watt.

Among the proofs of this stationary or retrograding system, I will adduce the boilers originally placed in the "Liverpool." I will give the details of those boilers, and the several efforts, on the part of the engineers, to remedy what I will show were inherent defects, and instances of contempt for those chemical principles on which combustion and the right use of fuel alone depend. I will show, that the cause of that wasteful expenditure of coals which marked the first voyage of the "Liverpool" was alone induced by the original mal-construction of the boilers, with their twenty furnaces;—by the injudicious mode of placing them in the vessel;—and the facility thus afforded to mismanagement in their working; and that this latter, combined with the absence of sound judgment, in this instance, on the part of those in command, and an unnecessary and wasteful expenditure of fuel at the time when common sense would have suggested its being economized and reserved, were the direct causes of the failure which attended the first attempt of that vessel to cross the Atlantic. I will, from these facts, show, that, however well-judged and considerate may be the plans of the directors of steam companies; however spirited may be their efforts to have every thing as perfect and efficient as money or determination can make it; still, the comparative efficiency of a steam-vessel—the satisfaction and patronage of the public—and the general success of the speculation will mainly depend on the manner in which the engineer performs his part.

Whether the following pages may succeed in leading to a diminution of those evils which accompany the use of coal in our furnaces, remains to be proved. They will, at least, give a different, and, I trust, a more practical and useful, direction to the inquiries of other labourers in the same vineyard.

I conclude these prefatory observations with the unequivocal assertion, that, if we study the chemical principles on which combustion is effected, and which I have endeavoured to explain, and if we apply those principles to practice in the manner I have pointed out, we shall not only be enabled effectually to banish smoke, with its numerous and accompanying inconveniences, from our towns and manufactories, but, at the same time, considerably increase the effective power of our furnaces, and thus add economy to comfort.

With this remark I submit the following pages to the notice of all who are interested in the subject.

INTRODUCTION.

"THE economy of fuel is the secret of the economy of the Steam-engine: it is the fountain of its power and the adopted measure of its effects. Whatever, therefore, conduces to *increase the efficacy of coal and to diminish the cost of its use*, directly tends to augment the value of the Steam-engine and to enlarge the field of its operations."

In these words Mr. Josiah Parkes introduces a valuable communication to the Institution of Civil Engineers, on "The Evaporation of Water from Steam-boilers," and I cannot find a more appropriate introduction to the present tract. Believing, also, with Mr. Parkes, that "we are yet far from having obtained either a complete knowledge of *the most profitable manner of submitting coal to the process of combustion*, or applying the caloric so obtained to the generation of steam," I submit the following pages to the consideration of the public, and, especially, to mechanical engineers, as a step towards obtaining that desired knowledge.

Mr. Parkes, in his several communications, has investigated and compared, with a masterly hand, the peculiar properties of the several classes of boilers, as exemplified in practice, and their respective merits as evaporative vessels

These, with the perspicuous and comprehensive tables appended to them, throw much light on this department of the production and application of steam power. One important branch of the subject remains to be inquired into, namely, the operations carried on in that great alembic, *the furnace—chemically considered;* and the adapting its arrangements so as to give full practical effect to the several processes which constitute combustion.

Taking these in their proper order, in treating on Steam and the Steam-engine, the subject divides itself into the following heads:—First, the management of *fuel* in the generation of *heat;* secondly, the management of *heat* in the generation of *steam;* thirdly, the management of *steam* in the generation of *power.* The first is in the department of the *furnace*, the second of the *boiler*, the third of the *engine.*

The object of the present tract is the examination of the various circumstances connected with the generation of heat from fuel; in a word, all that pertains to the first of these heads, *the furnace;* the two others having already formed the subject of many able inquiries, by practical and scientific men. That which belongs to the construction of the *engine*, and the endless varieties of *boilers*, belongs to the several departments of mechanical *engineering:* that which belongs to the construction of the *furnace*, however, in aid of the combustion of fuel and the generation of heat, is strictly and exclusively within the department of *chemistry.*

That this branch of the subject has been so much neglected is, in a great degree, owing to its having been confounded with the *boiler*, by which it fell into the department of those who were not likely to have studied the complicated chemical details which relate to combustion.

One object contemplated in the following pages is, to disconnect this division of the subject from that branch of manufacture—*boiler-making*, with which it has too long been associated; and either take it out of the hands of the working bricklayer and others employed under the mechanical engineer, or, what I hope to be able to effect, convey to that class of persons such an acquaintance with the chemistry of the subject as will qualify them for judging what is right or wrong in the management of fuel.

That the subject under consideration is strictly *chemical* will be acknowledged when we look into its details, were any further proof necessary beyond the fact, that to the investigation of the mysterious process we call *combustion*, were the great talents and energies of that illustrious man, Sir Humphry Davy, long and anxiously directed;—that to his labours and discoveries in this branch of chemical science much of his fame is attributable;—and that, to this day, his opinions are received as the highest authority by the whole scientific world.

The subject before us involves a consideration of the nature and properties of the various kinds of fuel: it examines the chemical action of their several constituents on each other: it seeks to apply those inquiries to the class of chemical results which may be useful, and to avoid those which are mischievous: it investigates a very difficult branch of chemistry—that of gaseous formations, and their numerous and complex properties, combinations, and equivalents.

It involves, also, in an especial degree, the closest observation on the separate influence which each of the constituents of atmospheric air exercises on combustible bodies in the generation of those extraordinary elements of nature, *heat* and *light;* and, finally, it investigates the cause and character of *flame* and *smoke*, and the influence these have on the former. The combustion of bituminous coal, in fact, involves a greater number of distinct natural phenomena and chemical results than almost any one process in the whole range of philosophical inquiry. A knowledge of these results, at least a correct observation of the *modus operandi* by which nature proceeds, as far as practice demands, is then an essential ingredient in an inquiry after the best mode of carrying out the operations of the furnace and the forge.

It is not to be expected, that our firemen are to be chemists, or our engineers philosophers; but it is to be expected, in this age of rational research and inductive reasoning, that we should avoid manifest and unscientific blunders in our every-day manipulations. And when we look to the influential part which coals and other combustibles are destined to perform, we have no ordinary stimulus in searching out the right path and practice.

When we speak of burning coals under a boiler, the phrase conveys but an imperfect idea of what that operation is; and, in a scientific point of view, a very inaccurate and slovenly one. The combustion of coals under a boiler may take place to a large extent, and yet a very low calorific effect be obtained, and the water evaporated thereby, that is, the amount of *duty performed*, or effect produced, may be much below what is rightly due to the *quantity* of fuel employed. Now, this I take to be the case, to a great extent, in the furnaces of all boilers, especially in *marine boilers*, and even in those connected with the justly celebrated Cornish engines. The extraordinary duty obtained from coal in Cornwall appears due to the excellent plan and arrangements of the boilers, particularly as to *dimensions*, as Mr. Parkes has satisfactorily shown; and also to the system of using steam *expansively*, in their engines, in a peculiar manner, and to a greater extent than in any other part of the kingdom, rather than to any improvement in the mode of effecting the combustion of the fuel. Indeed, it would appear, that the construction and arrangements of the *furnaces* in Cornwall are as deficient and unsound in principle as those adopted elsewhere.

In the following treatise I do not undertake to show how *the smoke* from coals can be *burned;* but I do undertake to show how *coals may be burned without smoke;* and this distinction involves the main question of economy of fuel.

When smoke is once produced in a furnace or flue, I believe it to be as difficult or impossible to burn it, so as to convert it to heating purposes, as it would be to convert the smoke issuing from the flame of a candle to the purposes of light; and this assertion I make in the face of so many patents, from so many ingenious men. If, indeed, we could collect the smoke and unburnt gases of a furnace, and separate them from the products of combustion which the flues carry off, they might, subsequently, be made instrumental to the purposes of light and heat; but that is impossible.

When we see smoke issuing from the flame of an ill-adjusted common lamp, we also find the flame itself dull and murky, and the heat and light diminished in quantity. Do we then attempt to *burn that smoke?* No; it would be impossible. Again, when we see a well-adjusted Argand lamp burn *without producing any smoke*, we also see the flame white and clear, and the quantity of heat and light increased. In this case, do we say the lamp *burns its smoke?* No; we say the lamp *burns without smoke.* This is the fact, and it remains to be shown why the same language may not be applied to the combustion of the same coal and the same gas, in the *furnace*, as in the *lamp*. Our object, then, should be to draw the same distinction and effect the same practical difference between our furnaces as they *ought to be*, and *as they are*, which we see between the Argand lamp and the common one. This treatise will, I trust, sufficiently show how this may be effected, and, by correcting the imperfections of the old plan, lead us to another and a better one.

It may be asked, how it has happened, that, hitherto, this has not been effected? I answer, because the *chemistry* of combustion has been *neglected*—not in the *laboratory*, but *in practice;* and because the construction of our furnaces has been too much left to those who know little of the chemical properties of the materials which are consumed in them. To this day, the construction and arrangement of the furnaces, in our manufactories, and under the boilers of the steam-engines, are in the hands of bricklayers, working boiler-makers, and other individuals—ingenious in their respective departments, but who should not be expected to be acquainted with the details of another department so different as that of chemistry; and whose habits and business cannot have led them to investigate or study chemical agencies and processes; yet, on these agencies is the whole question of the efficacy of a furnace dependant.

Are, then, our bricklayers or boiler-makers to become chemists? No. But those who direct—those who assume the charge of teaching them to construct the numerous descriptions of furnaces with which this country abounds, should be masters of the leading principles on which their art is based and the success of their operation depends; and, I may add, in which the interest of their employers is so much concerned,

Besides, the required information, as I shall be able to show, is not so extensive as to be inconsistent with their other avocations; and I venture to say, if they study the facts and principles stated even in this treatise, their eyes will at least be opened to the folly of many of those "*smoke-burning*" expedients which of late years have incumbered the patent list, and induce them to admit, that the lights of chemistry alone can guide them safely in those departments of the arts in which combustion forms a part.

And if we only observe what progress has been made in many of the arts and processes around us;—for instance, in the arts of dyeing, bleaching, and glass-making; in the manufacture of the acids and alkalies; even in soap and candle making; and, above all, in the arts of gas making and gas burning—and all by the aid of chemistry; it may be asked, why not avail ourselves of this aid in extracting heat, as well as light, from coal? and in the combustion of gas in our *furnaces* as well as our *lamps?* Unfortunately, so many of our ingenious men have got on a wrong track, as I shall show in the course of these observations, that the current of invention has lately run even counter to the laws of chemistry, and to the works of those able men who should have been their only instructors.

In undertaking, myself, to lead others and to avoid the imputation of presumption, I observe, *in limine*, that I do not affect to give any new view of the nature of combustion, much less do I make any claim to discovery. What I take credit for is, the practical application, *on the large scale of the furnace*, of those chemical truths which are taught by the ablest chemist of the day, and so well known in every *laboratory*. I also take credit for bringing together the detailed and scattered facts and illustrations of such authorities as bear on the subject before us, and of so arranging and applying them, (with such additional illustrations as appeared to me conducive to the object in view,) as will, I trust, enable practical men, without going deeper into the science than is compatible with their time and other avocations, to understand that part which chemistry has to act in the construction, arrangements, and working of our furnaces. By this means only will they be enabled to neutralize that opposition and counteraction which ignorance and prejudice, under the assumed, though erroneous, title of "*practice*," are so apt to give to the suggestions of science. This disposition to counteract our efforts we may deplore, but cannot prevent. All thinking practical men acknowledge it to be a main ingredient in retarding the onward march of improvement, though to a less extent, certainly, in our days than formerly; and it is, therefore, the more important, that mechanical engineers, in whose department these matters principally lie, should see the reason and understand the principles on which so much of their success depends.

SECTION I.

OF THE CONSTITUENTS OF COAL, AND THE GENERATION OF COAL GAS.

In a treatise, purporting to describe the means of obtaining the largest quantity of heat from coal, the first step naturally should be an inquiry into the several varieties of that combustible and its respective constituents, for the purpose of ascertaining the inherent power of each for giving out heat. However interesting and useful such an inquiry would be, it is not essential to that practical view of the subject to which I would confine these observations; and, as it would lead too much into detail, I merely give the following outline, which will be sufficient for our present purpose.

The classification of the various kinds of coal and their respective volatile products, coke and ashes, according to Dr. Thomson, are as follows:

1,000 *parts of*	*Weight of volatile product.*	*Weight of Coke.*	*Incombustible Ashes.*
Caking Coal gives	226	774	15
Splint Coal	352	647	95
Cherry Coal	447	522	100
Cannel Coal	600	400	110

More in detail, these varieties are composed of

	Caking Coal.	*Splint Coal.*	*Cherry Coal.*	*Cannel Coal.*
Carbon	75·28	75·00	74·45	64·72
Hydrogen	4·18	6·25	12·40	21·56
Nitrogen	15·96	6·25	10·22	13·72
Oxygen	4·58	12·50	2·93	0·00
	100·00	100·00	100·00	100·00

Dr. Ure's analysis, which is considered more correct, is as follows:

	Cannel Coal.	*Splint Coal.*
Carbon	72·22	70·90
Hydrogen	3·93	4·30
Nitrogen	2·80	0·00
Oxygen	21·05	24·80
	100·00	100·00

From the details of an elaborate and apparently accurate analysis, made by Mr. Thomas Richardson, with the aid of Professor Leibig,* I extract the following; and which, it will be seen, varies essentially from the preceding:

TABLE I.

Species of Coal.	Locality.	Carbon.	Hydrogen.	Azote and Oxygen.	Ashes.
Splint	Wylam	74·823	6·180	5·085	13·912
"	Glasgow	82·924	5·491	10·457	1·128
Cannel	Lancashire	83·753	5·660	8·039	2·548
"	Edinburgh	67·597	5·405	12·432	14·566
Cherry	Newcastle	84·846	5·048	8·430	1·676
"	Glasgow	81·204	5·452	11·923	1·421
Caking	Newcastle	87·952	5·239	5·416	1·393
"	Durham	83·274	5·171	9·036	2·519

TABLE II.

Species of Coal.	Locality.	Quantity of Oxygen necessary to the perfect combustion of 100 parts of Coal, subtracting the Oxygen contained in the Coal.	Relative quantity of Heat given out by the same weight of Coal. Edinboro 100·00	Relative quantity of Heat given out by the same volume of Coal. Edinboro 100·00
Splint	Wylam	240·1	110·34	108·99
"	Glasgow	250·5	115·12	114·15
Cannel	Lancashire	256·4	117·83	117·91
"	Edinburgh	217·6	100·00	100·00
Cherry	Newcastle	253·9	116·68	112·07
"	Glasgow	244·9	112·12	107·78
Caking	Newcastle	266·7	122·56	119·03
"	Edinburgh	250·2	114·98	111·31

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* The analysis is given in detail, in a late number of the *Mining Review*.

“ The first table requires no explanation. The second table contains, in the first column, that quantity of oxygen which 100 parts of the different coals abstract from the air for perfect combustion. This quantity of oxygen expresses the relative heating power of the different coals, in admitting that the quantity of heat evolved by a combustible substance is *proportionable to the quantity of oxygen which is consumed in its perfect combustion.* This relation, according to weight and volume, is given in the second and third columns. For example, 100 volumes being taken, the Lancashire coal gives out more heat than the same volume of Edinburgh coal by a quantity expressed by 17·91 ; and 100 parts by weight being taken, the former coal surpasses the latter in the heat evolved by the quantity expressed by 17·83.”

I will not here offer any opinion on the above details, as, in the course of these observations, I shall have occasion to examine the influence which the relative proportions of the volatile and fixed constituents of coal have in the generation of heat. I have given the table of results, that we may have before us the leading characteristics of coal, and their carbonaceous and bituminous constituents, as ascertained by the latest experiments.

Mr. Josiah Parkes justly observes, in his first paper on boilers, “ Experiments are wanting on the relative *heating powers of coal and coke.*” And again, “ We have every element for the purpose of investigation and comparison excepting one, viz., the relative *strength of the coals* employed.” By this is meant the quantity of *effective, available heat* which the several descriptions of coals are capable of supplying, supposing such quantities of heat, respectively, to be the maximum result of *complete combustion.* Now, the only available test of the “ *strength of coal*” is the weight of water evaporated by any given weight of it. To measure the strength of coal, however, by this standard must be very fallacious, and, at least, can only be an approximation, until furnaces are more perfect, and the entire heating powers of coal shall have been obtained by *perfect combustion*.

"Notwithstanding the great stride," observes Mr. Parkes, "which has been made in the economy of fuel by the Cornish engineers, the *sources of waste* are still very great, and we may hope for great advance in evaporative economy, when *combustion, as a science and practical art*, has received the attention its merits."* This is not only good authority, but great encouragement, inasmuch as the evaporative economy of boilers, in relation to the effect produced by given weights of coal, has been more rigidly tested by him than by any who have preceded him, as far as the present system and construction of furnaces enabled him to draw conclusions.

The theory of combustion is now well understood by scientific men; but, as a *practical art*, it still remains at a very low ebb. The works of the able chemists of our own country sufficiently elucidate the several phenomena of combustion and chemical action, confirmed, as they are, by the researches of the first electrician of the day, Dr. Faraday; yet these lights of science have not been practically applied to the use of fuel in the arts and manufactures of this country.

We know, *scientifically*, that carburetted hydrogen and the other compounds of carbon require given quantities of atmospheric air to effect their combustion; yet, we adopt no means, *practically*, of ascertaining what *quantities* are supplied, and treat them as though no such proportions were necessary. We know, *scientifically*, the relative proportions in which the constituents of atmospheric air are combined; yet, *practically*, we appear wholly indifferent to the distinct nature of these constituents, or their effects in combustion. We know, *scientifically*, that the volume of any given weight of air or gas is in proportion to its rarefaction, and to the measure of its specific heat; yet, *practically*, we treat them, in their passage through the furnace, as though we were ignorant of the cause or effect of expansibility. We know, *scientifically*, the proportion of *condensation* and *expansion* due to the unions of the several compounds of hydrogen and carbon, and the products of their combustion; yet, *practically*, we treat them in the furnace as though we knew nothing of the changes produced by chemical action. We know, *scientifically*, that the inflammable gases are combustible only in proportion to *the degree of mixture* which is effected between them and the oxygen of the air; yet, *practically*, we never trouble our heads as to whether we have effected such mixture or not. These and many similar illustrations exhibit a reprehensible degree of carelessness, which can only be corrected by a sounder and more scientific knowledge of the subject on the part of practical engineers and manufacturers; and this can only be attained *through the aid of chemistry*. To this latter I am, therefore, desirous of directing attention.

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* These and the subsequent communications by Mr. Parkes, published by the Institution of Civil Engineers in their transactions, should be consulted by boiler-makers and engineers, as they embrace, in the most comprehensive form, the results, comparatively arranged, of the most accurate experiments in the several kinds of boilers and engines now in use.

The main constituents of all coal, as we see in the preceding tables, are *carbon* and *hydrogen*.* To these are added various proportions of sulphur, oxides of iron and other metals, carbonate of lime, magnesia, silica, alumina, and other earthy incombustible matter.

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* We see that portions of oxygen and nitrogen are usually found combined in coal. As these, however, do not add to, or abstract from, the quantity of heat generated from the *combustible* ingredients, and as it is a matter of great doubt how they are combined, they may be considered as neuter, as regards the investigation before us; I have, therefore, taken no further notice of them.

It is not necessary here to go more into detail respecting several compounds which exist in coal, or their effect on combustion: sufficient for our purpose to know, that they are all more or less injurious, with the exception of the *carbon* and the *hydrogen;* and that these latter are the bases of the two leading characteristics of coal, as described by chemists, viz., the carbonaceous, or solid, and the bituminous, or volatile portions. Without going further into the nature and properties of coal, it will, therefore, be sufficient that we take these two leading, well known, and admitted divisions, and consider the subject of combustion with reference to them alone.

Professor Brande, on this head, observes: "Carbon and hydrogen unite in several proportions and form many curious and important compounds, among which it is sometimes difficult to distinguish those which ought to be considered as distinct and definite combinations from others which are, probably, indefinite mixtures of the former. These compounds are, generally, termed hydrocarbons, and amongst them are some striking illustrations of one species of isomerism; that is, of compounds differing often essentially in their physical or chemical properties, or both, and, yet, apparently produced by the union of the *same elements* and bearing the *same relation* to each other."

Here we have, from the pen of this able professor, sufficient to satisfy us how intricate are the combinations and effects produced by the agents with which we have to deal. In the combustion of coal in our furnaces we have several varying compounds of the most powerful agents to which chemistry has introduced us, viz., carbon, hydrogen, oxygen, nitrogen, and sulphur, with their numerous combinations; and what a field of inquiry does this enumeration open to our view; yet, what proofs does every step in the inquiry afford of the difference between the extent of our scientific acquaintance with the subject and its practical application. In pursuing the investigation, however, we must not be deterred by this apparent labyrinth of difficulties. Our business is with facts; to collect, arrange, and apply them to our several purposes, and, where we cannot develop the causes, to rest satisfied with the effects produced, and turn those effects to the business of life.

In the natural state of coal, the bitumen and carbon are united and solid. Their respective characters and modes of entering into combustion are, however, essentially different; and to our neglect of this primary distinction is referable much of the difficulty and complication which attend the use of coal on the large scale of our furnaces.

The first leading distinction is, that the bituminous portion is convertible to the purposes of heat in the *gaseous state alone;* while the carbonaceous portion, on the contrary, is combustible *only in the solid state;* and, what is essential to be borne in mind, *neither can be consumed while they remain united.* The fact of this necessary *separation, previously to combustion,* is opposed to the popular notion adopted by many practical men, whose language and proceedings show that they have considered coal *(as regards the process of combustion)* to be a homogeneous body; or, at least, as susceptible of being treated by a single operation, and capable of being ignited while in the state of *solid coal;* yet, nothing can be more essentially distinct in the whole range of laboratory operations than the treatment of *solid* and *gaseous* bodies.

Indeed, the use of the term "*fuel,*" as applied to the combustion of coal during its several processes in the furnace, without reference to any particular constituent, or the state, whether gaseous or solid, in which it exists at the time, is sufficiently indicative of the inaccuracy and inattention to the chemical conditions and combustion to which I am referring.*

This leads us to the first circumstance connected with the combustion of coal, which is overlooked in practice, and, as far as I have seen, not sufficiently identified by those who have written on the subject: I mean, the *negative* character of coal as a heat-giving medium, or, more correctly speaking, its *positive* character as a *cooling* medium, so long as the bituminous constituents remain united with the carbonaceous, or are in *process of volatilization.*

This circumstance, we shall hereafter find, merits particular attention, inasmuch as it exercises great influence during certain stages of the progress towards combustion, and, therefore, demands peculiar management; and as it is the direct cause of those undue and injurious fluctuations of general temperature in the body of the furnace, which too often derange the evaporative functions of the boiler.

The general impression among practical men is, that coal, spoken of under the objectionable term of "*fuel,*" enters into combustion *at once*, on the application of heat, in the furnace; and that, *during such combustion*, it evolves the gaseous matter which it contained. This, however, is neither correct nor scientific, and evades an important feature in the use of coal, namely, *the order* in which the gaseous and solid portions come into use as heat-giving media. Let us examine this more closely and in detail.

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* Many instances of the mode of considering the combustion of coal might here be given: they will, however, be familiar to most readers. The following will suffice to explain my meaning. In a popular treatise on the steam-engine, by Dr. Lardner, the author, speaking of Brunton's revolving grate, observes, "The coals are let down from the hopper on the grate, at that part which is most remote from the flue, and, as they descend in very small quantities at a time, *they are almost immediately ignited.*" Here the *coal* is represented as being *ignited*, or converted into flame, which is incorrect. *Coal-gas* may be converted into flame, and *coke* may be ignited, but *coal* can neither be ignited nor converted into flame.

Again, "But, until their ignition is complete," (meaning, until the whole of the gas is expelled,) "a *smoke* will arise, which, passing to the flue over the burning coal, *will be ignited.*" Here it is the *gas* which is ignited—the term *smoke* being improperly used instead of *gas*. This, also, is incorrect, as *smoke*, properly speaking, being once formed, cannot be ignited or inflamed in the way, or by the means, here stated, at least, in the same furnace.

I do not mean to say the author was ignorant of these facts; indeed, I am persuaded of the contrary. I merely quote the passages as a proof of the want of attention to chemical propriety and accuracy in the terms used when treating on a subject so purely chemical, and the adoption of terms by which popular error is too often confirmed and extended.

When heat is first applied to bituminous coal, the question naturally arises, What becomes of it? or, What is its effect? An ordinary observer would say, it will directly increase the general temperature of a furnace, by bringing into activity an additional mass of combustible matter. *Ultimately*, it will have that effect; but we are now inquiring, strictly and chemically, into the several *progressive stages* of combustion, and must not deceive ourselves by general conclusions, to the neglect of those intermediate circumstances from which important results arise, or which may require special arrangements; and the circumstance I am now drawing attention to is just of such a character.

A charge of fresh coal thrown on a furnace already in an active state, so far from augmenting the general temperature, or *giving out* heat, becomes at once an *absorbent* of it. This cannot have escaped observation, although the *extent* to which this absorbing process is operative, the cause of this absorption, the circumstances which accompany it, and its immediate consequences, seem to be very inadequately appreciated.

This heat, so absorbed, becomes at once the source of the *expansion* and *volatilization* of the bituminous portion of the coal; in a word, of the generation of the gas: the absorption of the one being in an exact ratio to the generation of the other. Now, volatilization is the most cooling process of nature, by reason of the enormous quantity of heat which is directly converted from the *sensible* to the *latent* state; and this absorption of heat, *taken from the general mass in the furnace* and appropriated, as it were, by the coal to its own purposes of gasefaction, goes on until the whole of its volatilizable constituents have been thus winged for flight.

The bitumen of the coal, by reason of the great porportion of hydrogen which it contains, (and which is its main constituent,) absorbs heat with great avidity, the first result of which is its change from the state of a *solid*, to that of a *tarry, viscous semifluid*;* and, subsequently, by further increments of heat, to the state of gas, with its enormously expanded volume. The effect is, that the large quantity of heat so absorbed, and become latent in the gas, is wholly unavailable for the business of the furnace, and must continue so until such gas enters into *chemical* union with oxygen, and is consumed.

The continuance in such fused or semi-fluid state being but temporary, we cannot, as we do in the case of water, retain it, and ascertain the exact quantity of heat due to this specific state of *semifluidity*. Hence, we are apt to overlook, or underrate, its faculty of absorption; and so also of the still greater degree of latent heat due to its *gaseous* state. Had we the power of condensing it, as we do when we condense steam, we should, in like manner, be able to ascertain the quantity of its latent heat. On these points it is instructive to consider the phenomenon, now so well understood, of the absorption of heat by water, during its expansion and volatilization;—the conversion of coal into gas being strictly analogous, in principle, to the conversion of ice into water, and water into steam.

We know that the heat of fluidity of water is 140, while that of its elastic fluidity, or state of steam, is 1000, accompanied by an expansion of 1800 times its bulk or volume.

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* Coke is increased in bulk nearly one-third beyond that of coal: a proof of the viscous, fused state in which it had been before the separation of the bitumen.

What the corresponding numbers are, with respect to the *semifluid* and *gaseous* states of the bitumen of the coal, has not been ascertained, but cannot be taken at a lower estimate.

We know, however, that heat, where it can be absorbed, produces expansion, and that it only ceases to be absorbed when the capacity of the body for retaining it is satisfied; that is, when no more heat can be retained without a further *change of condition* or form, and when all further increments of heat would pass off in a *sensible* state, by conduction or radiation, as fast as received, and become appreciable by the thermometer.

Thus, we see how the relation between the consecutive changes induced by heat in ice, from solid to liquid, and liquid to vapour or steam, is a correct type of what takes place between the solid, semifluid, and gaseous state of the bituminous portion of coal. Thus, also, we understand how coal thrown on a fire can have no *direct operation as a heat-giving body*, until, through its successive changes in form, character, and faculty of absorbing heat, its maximum power of retention has been reached, and its gaseous state assumed.

We now see, that every fresh charge becomes, *pro tanto*, an absolute refrigerator in the furnace, both mechanically and chemically. *Mechanically*, by its interposition between the glowing coals on the bars and the boiler, and thus intercepting radiation. *Chemically*, by the conversion of so large a quantity of heat (which would otherwise have worked the work of evaporation) from the sensible, thermometric state, to the insensible, latent state, in the gas.

The *first* of these sources of the cooling influence of a fresh charge of coals is alone what, in practice, is attended to; while the *second*, though much more influential, is disregarded or unknown. Of this, however, we shall have to take further notice, inasmuch as it is an injurious accompaniment of the act of charging a furnace.

And here I would draw attention to the distinction, in point of *time*, which this process of gasefaction necessarily produces between the combustion of the two constituents, the carbon and the bitumen. So long as any of the bituminous constituents remain to be evolved from any atom or division of the coal, its solid, or carbonaceous part remains black, at a comparatively low temperature, and utterly inoperative as a heating body. This, we have seen, arises from the circumstance of the entire accessible heat being absorbed and carried off by the bitumen during its expansion and volatilization;—such heat being, in fact, the cause and element of its volatility; whereas, the carbonaceous portion of such atom or division remains, without any increase of temperature, under the "*cooling process of gasefaction*," (as Dr. Ure terms it,) beyond that which is required for expelling the gas. In other words, the carbonaceous part has *to wait its turn* for that accession of heat which is essential to its own progress towards combustion, and in its own peculiar way, as will be explained hereafter.

The whole of this process, preparatory to the combustion of the gas, is well illustrated by what takes place in our gas-making establishments, and which exhibit the great quantity of heat required for this conversion; yet, this loss, or appropriation of heat is strangely overlooked when operating with coal in the furnace. Now, we cannot be insensible to the fact, that whatever coal is used and heat employed *outside* the retorts, in our gas-works, is employed solely in expanding and expelling the bituminous matter, in the shape of gas, from the coal which is placed *inside* those retorts; and that a corresponding expenditure of heat must take place when we expel the gas from the coals in our furnaces; or, in fact, wherever gas is generated.

In the *retorts*, however, no loss is sustained, the entire of the gas generated being collected and retained for subsequent combustion; whereas, having no power of retaining it under the arrangements of a *furnace*, much of it is there unavoidably lost. Thus, after the bituminous portion of the coal has so exhausted the furnace by this cooling process, (its own gasefaction,) if we suffer it to escape without combustion, (and which, in most cases, is the fact to a considerable extent,) we are losers of *absolute*, effective heat, to the entire extent of what has been so taken up: and, *prospectively*, to the extent of what it would have given out, had it duly entered into union and combustion with its equivalent of oxygen.

We also see, that if this bituminous part, so converted into gas, at such an expense of heat from the furnace, be not consumed and turned to account, it would have been better had it not existed in the coal; as such heat would, in that case, have been saved and become available for the business of the furnace. To this circumstance may be attributed the alleged comparatively greater heating properties of coke, or anthracite, over bituminous coal; not that the former has, in fact, the property of imparting more heat, weight for weight, but that the latter, by reason of the fugitive gaseous character of its bituminous portion, and the physical and chemical impediments to its entire combustion, presents greater practical difficulty in bringing its heating powers to account; no such difficulty occuring in the use of coke. The entire of the bituminous constituents being thus expelled, the second, or carbonaceous constituent remains. This, in the retorts, is called *coke*, and, as we shall hereafter have to observe, cannot, *by itself*, be reduced to a gaseous state.

Thus we have before us not only the elementary constituents of coal, but their subsequent separation under the forms of solid and gaseous bodies. The importance of this distinction will be better understood as we proceed. Much confusion at present prevails in all that regards the use of coals in a furnace, by disregarding the several distinct processes to which we have been referring, and *the order* of their succession, viz., the expansion and fusion of the bitumen; the generation of the gas; its absorption of heat during such expansion; its combustion; the subsequent combustion of the solid carbon, and so on: for if not managed with due attention to the peculiarities and wants of each, these several processes interfere with and mar each other's effect. Now, these distinctions and their modifications, which will be noticed as we proceed, involve the whole question of perfect or imperfect combustion, and by which economy or waste is to be induced. In commenting on these several heads, I will be as explicit as possible, without going more into scientific detail than may be consistent with the means and opportunities of that class of practical mechanics for whom I write.

The point next under consideration will be, the peculiarities, processes, and general phenomena incident to the combustion of the *gaseous portion* of the coal, as distinct from the *carbonaceous* or *solid* portion.

SECTION II.

OF GASEOUS COMBINATIONS, AND PARTICULARLY OF THE UNION OF COAL GAS AND AIR.

Having pointed out the leading characteristic in the use of coals, arising out of its elementary divisions, *bituminous* and *carbonaceous*, namely, that the first is available only in the *state of gas*, and the second in that of a *solid;* and having explained the first process of gasefaction, our next step in the progress towards the combustion of this gaseous portion is, its union with atmospheric air. This part of the subject will require the more attention, as the greater portion of the practicable economy in the use of coal will be found connected with the combustion of the gases; and as the numerous combinations of which they are susceptible embrace the whole range of temperature, from that of flame down to a refrigeratory effect.

The subject of gaseous combinations, then, is, without exception, the most important in the inquiry before us; and those who would study the economy of fuel, and the obtaining from it the greatest quantity of heat, cannot dispense with this branch of it,—it is the alpha and omega of the process of combustion. The mechanical engineer may ask, What has this to do with boiler-making or furnace-building? I tell him, it involves the whole question of right or wrong in these trades: and, hereafter, it will be admitted, that, if ignorant of this branch of chemistry, he must be ignorant of the first principles of his business, so long as a furnace is to be part of a boiler, and that coals are to be consumed in that furnace.

On the application of heat to bituminous coal, the first result, as already mentioned, is its absorption by the coal, and the consequent disengagement of gas, from which all that subsequently bears the character of flame is exclusively derivable. This gas, whether it be in a close retort or in a furnace, is associated with several other substances more or less tending to deteriorate its inflammable properties and powers of giving out heat and light. In the preparation of gas for illuminating purposes, these impurities are separated, and the pure gas alone employed. As, however, this separation cannot be effected in the furnace, and as the entire gaseous products of the coal, good and bad, are indiscriminately mixed, and necessarily consumed together as they are generated, it is the more incumbent on us to be cautious, lest, by any injudicious arrangement, we force these impurities into a more active energy, and thus increase their deleterious agency.

We will not stop here to consider the nature of those impurities arising out of the unions of sulphur, and the other injurious constituents of coal, although they exercise a considerable, and even a mischievous influence on the calorific effect of the burning gas in the furnace; but will take those constituents alone which unite in forming the *useful* gases, and from which we are to derive heat.

These constituents are the *hydrogen* and the *carbon: and* the unions which alone concern us here are, first, *carburetted hydrogen*, and, second, *bi-carburetted hydrogen*, commonly called olefiant gas. These two, and their unions with the air, in the process of combustion, we are now about to examine.

Our object being to obtain heat by the combustion of these inflammable gases, this is the place for a few remarks on the nature of *combustion*, and, particularly, as regards *gaseous* matter, without going deeper into the subject than is necessary for its practical application.

Gases, as well as other bodies endowed with the power of giving out heat and light, have been called *combustibles*. This term has been a source of much error in practice, from a misconception of its meaning, under the impression that combustibles possess, in some undefined manner, and within themselves, the faculty of burning; and, although every one knows that they *cannot burn without air*, still, the part which air has to act in the process is but little inquired into by unscientific men. It is, indeed, within our own time that the nature of this union of the gas with the air has come to be better understood; and, although the abstract question, as regards the immediate cause of that chemical action which we call combustion, may continue to be disputed, and new theories continue to be broached, still, for all practical purposes, it is now sufficiently defined and understood.

Here we are called on to inquire, with reference to the gases under consideration,—Whether there are any peculiarities or conditions which can influence the amount of heat to be obtained from them? and, if so, what they are. This again involves other questions with reference to *air*, and the part which it has to act in the process; and thus we are introduced, at once, into the *chemistry of combustion*.

One advantage of viewing the subject in this light is, that we shall see how idle would be any calculation or arrangement as to the dimensions or details of a furnace, before we had well examined and understood the rationale of that process on which those details must necessarily be contingent. For what chemist would begin by deciding on the dimensions of his retort or other apparatus, before he had considered the particular process to which they were to be applied; or the nature, properties, and tendencies of the materials with which he was about to operate? Yet, such is the every-day practice of those who profess to instruct us in the economy of fuel and heat; and, as Tredgold and others have done, give precise formulæ for deciding to a fraction the dimensions and details of our furnaces in which the operation of combustion, both of solids and gases, is to be carried on, while they neglect inquiring into the nature of the process itself, or the characters of the materials to be employed. The absurdity of this practice and the dangers into which it leads practical men will be more apparent when we come to consider the several parts of the furnace, and the duties which belong to each.

Let us here take a different course. Let us begin at the beginning. Let us examine and understand the nature of the process to which we are about to submit our materials, and their respective peculiarities, conditions, and wants, during combustion, before we determine the size or shape of the vessel in which the operation is to be conducted. Let us thus qualify ourselves to decide on secondary considerations, by a thorough knowledge of the primary ones by which they are to be regulated. With these preliminaries, we go rationally, systematically, and satisfactorily to work; otherwise, our labour will be vain, and only produce disappointment and loss.

Combustibility, then, is not a quality of the combustible, *taken by itself*. It is merely a faculty which may be brought into action through the instrumentality of a corresponding faculty in some other body. It is, in the case now before us, the union of the *combustible* with *oxygen*, and which, for this reason, is called the "*supporter*";* neither of which, however, *when taken alone*, can be consumed.†

To effect combustion, then, we must have a *combustible* and a *supporter* of combustion. Strictly speaking, combustion means *union;* but it means *chemical* union—one of the accompanying incidents of this kind of union being the emission of heat and light. What the nature of heat is; or the manner in which it is associated with matter; or how it is liberated during chemical action; and whether it is caused by electric, or by what other influence, is not here to be considered. Sufficient for our present purpose is the fact, that the chemical union of the *combustible* and the *supporter*, under certain now well-known conditions, is, for us, the cause of heat; and, further, that exactly in the ratio that such union is complete is the quantity of heat increased.

But we have not the means of obtaining this necessary *supporter*, this *oxygen*, in sufficient quantity, in a *separate* state, except at an expense which would render it incompatible with the purposes of a furnace. Our only alternative, then, is to apply to the *atmosphere*, of which it forms a part, to satisfy our wants. Had we to purchase or manufacture this oxygen, as Mr. Gurney does, in procuring the supply for his " Bude light", we should, necessarily, be more economic of its use, and inquire more respecting its application. But, finding an abundant supply at hand in the atmosphere, and obtaining it without expense, we are careless of its use, and take no note of the large quantity of noxious ingredients with which it comes accompanied. Hence many of the evils to which I am about to draw attention.

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* The term "*supporter*", as applied to oxygen, and as indicative of its office in the process of combustion, appears both injudicious and defective. Where two bodies unite to produce a given effect, the presence of both, as in this case, being *equally* essential in the production of light and heat, the term "supporter" would be *equally* applicable to the one as to the other. The French chemists have adopted a term for which we have no corresponding one in English, namely, "*comburant*", meaning, a body which *burns with* another.

† "In ordinary language, a body is said to burn when its elements unite with the oxygen of the air, and form new products. One of the bodies, as hydrogen, is termed the burning or combustible body, and the oxygen is said to be the supporter of combustion; but this language, although convenient for common use, is incorrect as a scientific expression, for oxygen may be burned in a vessel of hydrogen, as well as hydrogen in a vessel of oxygen, the one and the other being equally active in the process, and being related to each other in every way alike."—*Elements of Chemistry, by Robert Kane, M.D.:* Part i., p. 285. 1840.

The unions we have now to examine are those which take place between the constituents of the coal and those of atmospheric air, namely, the hydrogen and carbon of the former and the oxygen of the latter. Dr. Ure calls the carbonaceous part of coal " the main heat-giving constituent." In this he must be understood to include that portion of the carbon which forms one of the constituents of the gases alluded to; and, although, for the purposes of the *furnace*, so much value is set on the solid carbonaceous portion—*the coke*, we must not, on that account, undervalue the heat-giving properties of *the gas*. Indeed, the extent of those powers is strikingly brought before us by the fact, that, for every ton of 20 cwt. of bituminous coal, no less than 10,000 cubic feet of gas are obtained, for which we pay at the rate of 10s. for every 1,000 feet: the heating and lighting properties of the *gaseous portions alone* of one ton of coals thus costing five pounds sterling.

When, therefore, we consider the immense heating powers which such a mass of flame as 10,000 cubic feet of gas produces, we cannot resist the conclusion, that there must be something essentially wrong in the mode of bringing it into action *within a furnace*, as compared to its well-known efficacy *in an Argand burner*. That this is the fact will appear manifest as we proceed: and one of my objects is to show how the combustion of the volatile portions of coal may be effected as completely, when issuing from the throat of a furnace, as from the beak of a gas-burner.

Let us bear in mind, that coal gas, whether generated in a retort or a furnace, is essentially the same; although, in the latter case, it is accompanied by the impurities which I have alluded to. Again, that, strictly speaking, it is not inflammable; as, *by itself*, it can neither produce flame nor permit the continuance of flame in other bodies; and which is proved by the fact, that a lighted taper introduced into a jar of carburetted hydrogen, (coal gas,) so far from inflaming the gas, is itself instantly extinguished.

How, then, is it to be consumed and rendered available for the production of heat? The answer is, solely by effecting its *chemical union*—not with the *air*, as is the vulgar and dangerous notion, but with the *oxygen* of the air—the "supporter" of flame—the heat-giving constituent of the air—in *given quantities*, and at a *given temperature*.

This, at once, opens the main question,—What are these *quantities*, and what is this *temperature*, and are there any other *conditions* requisite for effecting the chemical union of the oxygen of the air with the inflammable gas, to *the best advantage?*

Effective combustion, for practical purposes, is, in truth, a question more as regards *the air* than the *gas;* and the former, as referable to our object, would appear better entitled to the term, combustible, than the latter, inasmuch as the heat is increased in proportion to the *quantity* of air we are enabled to use *advantageously*. Besides that we have no control over the gas after having thrown the coal on the furnace, though we *can* exercise a control over the air, as I shall show, in all the essentials to perfect combustion. It is this which has done so much for the perfection of the *lamp*, and may be made equally available for the *furnace*.

Now, although this control, and the management arising out of it, influences the question of perfect or imperfect combustion, and, therefore, affects that of economy; yet, strange to say, in an age when chemical science is so advanced, and in a matter so purely chemical, this is precisely what is least attended to in *practice*. The *how*, and the *when*, and the *where* this controlling influence over the admission and action of the air is to be exercised, are points demanding the most serious consideration, and can only be decided on *strict chemical principles*.

These points I propose examining under the following heads:

1st.—The *quantity* of air required for the combustion of the volatile portion of coal—the *gas*.

2d.—The *quantity* required for the combustion of the solid portion—the *carbon*, after the gas has been expelled.

3d.—The *quality* of the air so employed, particularly as regards the combustion of the *gas*.

4th.—The *incorporation* or diffusion of the air with the gas, and the *time* required for effecting the same.

5th.—The *mode* by which the incorporation of the air with the gas may be best effected.

6th.—The *place* where the air may, with the most effect, be introduced to the volatile and the solid or fixed portions, respectively.

SECTION III.

OF THE CONSTITUENTS OF COAL GAS, OR CARBURETTED HYDROGEN, AND THE QUANTITY OF AIR REQUIRED FOR THEIR COMBUSTION.

The first step towards effecting the perfect combustion of any combustible gas is the ascertaining the quantity of oxygen with which it will chemically combine, and the quantity of *air* required for supplying such quantity of *oxygen*. Here, then, we are called on for strict chemical proofs—these several quantities depending, not on the dictum of any chemist, but on the faculty which each particular gas possesses of combining with certain definite proportions of the other—the supporter; these respective proportions being termed "*equivalents*", or combining volumes. This doctrine of equivalents must, therefore, be understood before we can be prepared to admit the necessity of any precise quantities. This question, as to quantity, is also the more important when we consider, that the quantity of effective heat obtained by the combustion of any body will be in exact relation to the quantity of oxygen with which it will chemically combine.

Let us begin, then, by inquiring into the constitution of the coal gas, and the relative proportions in which its constituent elements are combined, as these necessarily govern the proportions in which it will combine with the oxygen of the air.

Now, the doctrine of "equivalents", that all-convincing proof of the truths of chemistry, being clearly defined and understood, reduces, to a mere matter of calculation, that which would otherwise be a complicated tissue of uncertainties. And let no mechanic feel alarmed at this introduction to "elementary atoms" and "chemical equivalents", or imagine it will demand a deeper knowledge of chemistry than is compatible with his sources of information: neither let him suppose he can dispense with the knowledge of this branch of the subject, if he has anything to do with the combustion of coal. Without it, he is at the mercy of every speculative "smoke-burning" pretender; whereas, with it, his mind will be at once opened to the simplicity and efficiency—I may add, to the truth and beauty of nature's processes, as regard combustion.

There is not, indeed, a more curious or instructive part of the inquiry than that respecting the conditions and proportions in which the compound gases enter into union with the constituents of the air: neither is there one more intimately connected with the practical details of our furnaces; these introductory remarks are, therefore, necessary for those who are not already familiar with it. Indeed, without some information on this head, the unions of the gases might appear capricious or uncertain; whereas, in fact, they are regulated by the most exact laws, and subject to the most unerring calculations.*

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* Mr. Parkes, observes:—"We are unfurnished with any definite, determinate experiments regarding the proportions in which *air* and *fuel* unite during combustion. We are, practically speaking, altogether ignorant of the mutual

Much of the apparent complexity which exists on this head arises from the disproportion between the relative *volumes*, or *bulk*, of the constituent atoms of the several gases, as compared with their respective *weights*.

For instance, an atom of *hydrogen* (meaning the smallest ultimate division into which it is supposed to be resolvable) is *double* the bulk of an atom of *carbon vapour;* yet the latter is *six times the weight* of the former.

Again, an atom of hydrogen is double the bulk of an atom of oxygen; yet the latter is *eight* times the weight of the former.

So of the constituents of atmospheric air—nitrogen and oxygen. An atom of the former is double the bulk of an atom of the latter; yet, in weight, it is as fourteen to eight.

A further source of apparent complexity arises from the faculty of condensation, or diminution of bulk, which, in certain cases, attends the *union* of the gases. For example, one volume of oxygen, and two volumes of hydrogen, *when united*, condense into a volume equal to that of the hydrogen alone (the weight being, of course, the sum of both); that is to say, one cubic foot of oxygen chemically combined with two cubic feet of hydrogen condense into the

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relations which subsist between the *combustible* and the *supporter of combustion* (the fuel and the oxygen); and, though we know, that, without oxygen, we cannot elicit heat from coal, we have yet to discover the most productive combinations of the two elements.

"Here, then, remains a wide field for research and experiment, worthy, and, indeed, requiring the labours of a profound chemist."

These matters are now better understood, and those "*most productive combinations*" rendered familiar and certain, by the labours of that "profound chemist", John Dalton, who first drew the attention of the chemical world to the subject of equivalent proportions, and taught us the importance and necessity of ascertaining those proportions—in fact, of "*reasoning by the aid of the balance.*"

Dalton's papers were first read before the Manchester Philosophical Society, and published in their memoirs in the year 1803. These volumes are very scarce, and I have not been able, anywhere, to meet with a complete copy of them. The Royal Institution, where Davy brought his great discoveries to light, contains but the five volumes of the first series. These volumes, or, at least, the papers of Dalton, should be republished, for the purpose of showing the correct chain of reasoning by which the mind of that acute philosopher proceeded.

bulk of two cubic feet: and so on, each union bearing its new ratio of volume and weight. This apparent complexity, however, we shall soon see give way to a systematic consideration of the subject.

I have stated, that there are two descriptions of hydrocarbon gases in the combustion of which we are concerned; both being generated in the furnace, and even at the same time, namely, the *carburetted* and *bi-carburetted* hydrogen gases. For the sake of simplifying the explanation, I will confine myself to the first, as forming the largest proportion of the gas to be consumed, namely, the carburetted hydrogen, or common *coal gas*, as I shall call it, for the sake of brevity.

Now, as, during combustion, the atoms of this gas become *decomposed*, and its constituents *separated;* and as these will be found to exercise separate influences during the process, it is essential that we examine them, as to their respective properties, weights, and volumes.

On analyzing this mixed gas, we find it to consist of two volumes of hydrogen and one of carbon vapour; the gross bulk of these three being *condensed into the bulk of a single atom of hydrogen;* that is, into two-fifths of their previous bulk, as shown in the annexed figures. Let figure 1 represent an atom of coal gas—carburetted hydrogen—with its constituents, carbon and hydrogen; the space enclosed by the lines representing the relative size or volume of each; and the numbers representing their respective weights—hydrogen being taken *as unity* both for volume and weight.*

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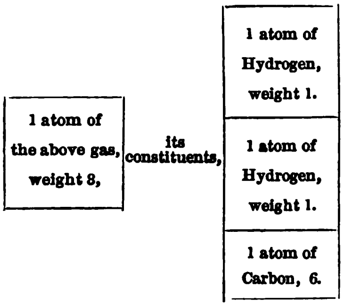
* "Ce gaz (carburetted hydrogen) est composé de 75·17 parties (by weight) de carbone, et 24·33 d'hydrogène; ou, d'un *volume* de carbone gazeux et quatre volumes de gaz hydrogène, condensés à la moitie due volume de ce dernier, ou, aux 2/5 du volume total du gaz, de manière que de cinq volumes simples, il n'en resulte pas plus de deux de la combinaison."—*Berzelius*, Vol. i., 330.

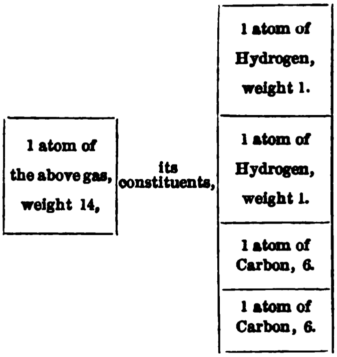
Carburetted Hydrogen.

Fig. 1.


1 atom of the above gas, weight 8,
its constituents,
1 atom of Hydrogen, weight 1.
1 atom of Hydrogen, weight 1.
1 atom of Carbon, 6.

Bi-carburetted Hydrogen.

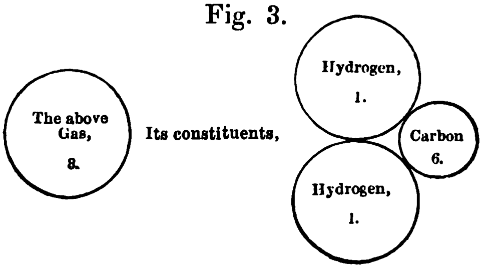
Fig. 2.


1 atom of the above gas, weight 14,
its constituents,
1 atom of Hydrogen, weight 1.
1 atom of Hydrogen, weight 1.
1 atom of Carbon, 6.
1 atom of Carbon, 6.

Or they may be represented thus :

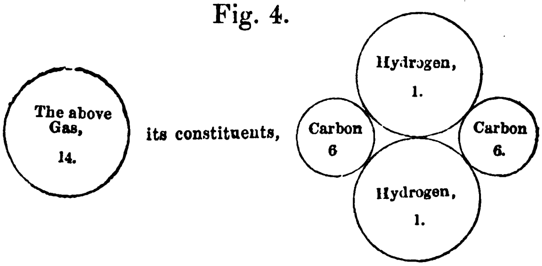
Carburetted Hydrogen.

Fig. 3.



Bi-carburetted Hydrogen.

Fig. 4.



Although not intending to take any further notice, in this place, of the *bi-carburetted* hydrogen, I have, however, annexed diagrams, figs. 2 and 4, representing this gas and its constituents, that both may be under view at the same time ; and by which it will be seen, that although, *in volume, the two gases are precisely the same, there is yet double the quantity of carbon in the bi-carburetted that there is in the carburetted hydrogen :* this circumstance is of great importance, and must be kept in our recollection, as these proportions will be found to have a considerable influence during the subsequent process of its combustion.*

I would here observe on the importance of keeping in mind this double relation of *weight* and *volume*, and the atomic constitution of these gases, as it will prevent much of that confusion which too often embarrasses those who are not familiar with the subject of gaseous combinations.

Let us now, in the same analytical manner, examine an atom of atmospheric air, the other ingredient in combustion.

Atmospheric air is composed of two atoms of nitrogen and one atom of oxygen; and here again we find a great disproportion between the relative volumes of these constituents; one atom of nitrogen being *double* the volume of an atom of oxygen, while there relative weights are as 14 to 8 : the gross *volume* of the nitrogen, in air, being thus four times that of the oxygen; and in *weight*, as 28 to 8, as shown in the annexed figure 5.

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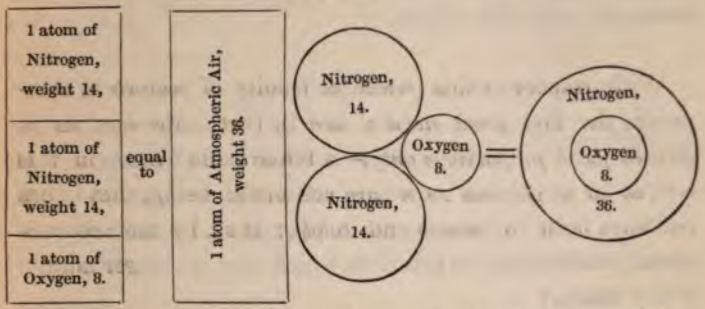
* The mode of representing the volumes of gas, by *rectangular* figures, as adopted by Mr. Brande and other chemists, is favourable, so far as *single atoms* are concerned, inasmuch as the eye at once recognises the relation between *volumes* and *half volumes*. As, however, I shall have to do with *masses* of these gases, I have adopted *circular* figures, the relation between the sizes of the volumes of the different gases being the same.

Atmospheric Air, *(or thus,)* *Atmospheric Air.*

Fig. 5.


1 atom of Nitrogen, weight 14,
1 atom of Nitrogen, weight 14,
1 atom of Oxygen, 8.
equal to
1 atom of Atmospheric Air, weight 36.
Nitrogen, 14.
Oxygen 8.
Nitrogen, 14.
Nitrogen,
Oxygen 8.
36.

Here we are relieved from the complexity arising out of any difference in *volume* between these constituents, when *united* and when *separate.* In the coal gas we found the constituents condensed into *two-fifths* of their gross bulk when separate: this, we see, is not the case with *air;* an atom of which is the same, *both as to bulk and weight*, as the sum of its constituents.

Thus, we find, the oxygen—the *heat-giving* constituent of the air, bears a proportion in volume to that of the nitrogen, as 1 to 5; there being, in fact, but 20 per cent. of oxygen in atmospheric air, and no less than 80 per cent. of nitrogen; a circumstance which should never be lost sight of in all that has to do with its admission and application.

Having shown the composition of coal gas, and also of air, with the weights and volumes of their respective constituents, we now proceed to the ascertaining the *separate quantity of oxygen required by each of those constituents*, so as to effect its perfect combustion, and produce the largest quantity of available heat; in other words, to find the "*chemical equivalent*", or volume of air, required for the saturation of this *mixed gas.*

Now, this is to be decided, not by the quantity of air we may admit or force into the furnace, but solely by the faculty with which each of these constituents is endowed of uniting *chemically* with the oxygen.

With respect to this power, or faculty of reciprocal saturation, the first great natural law is, that *bodies combine in certain fixed proportions only*,—a remarkable feature in this law, as far as gaseous bodies are concerned, being, that it has reference both to *volume* and *weight;* thus, by their concurrence, establishing the principle which now no longer admits of any doubt.[*]

The important bearings of this great elementary principle of proportionate combination cannot be more strikingly illustrated, or its influence rendered more familiar, than in the several combinations of which the elements of atmospheric air are susceptible, and the extraordinary changes of character and properties which accompany the changes, in the relative *quantities* alone, of the combining elements.

For instance, oxygen unites chemically with nitrogen in five different proportions, forming five distinct bodies, each essentially different from the others, thus:

Atoms.	*Weight.*	*Atoms.*	*Weight.*		*Gross Weight.*
1 of Nitrogen	14 unites with	1 of Oxygen	8 forming	Nitrous Oxide	22
1	14	2	16	Nitric Oxide	30
1	14	3	24	Hyponitrous Acid	38
1	14	4	32	Nitrous Acid	46
1	14	5	40	Nitric Acid	54

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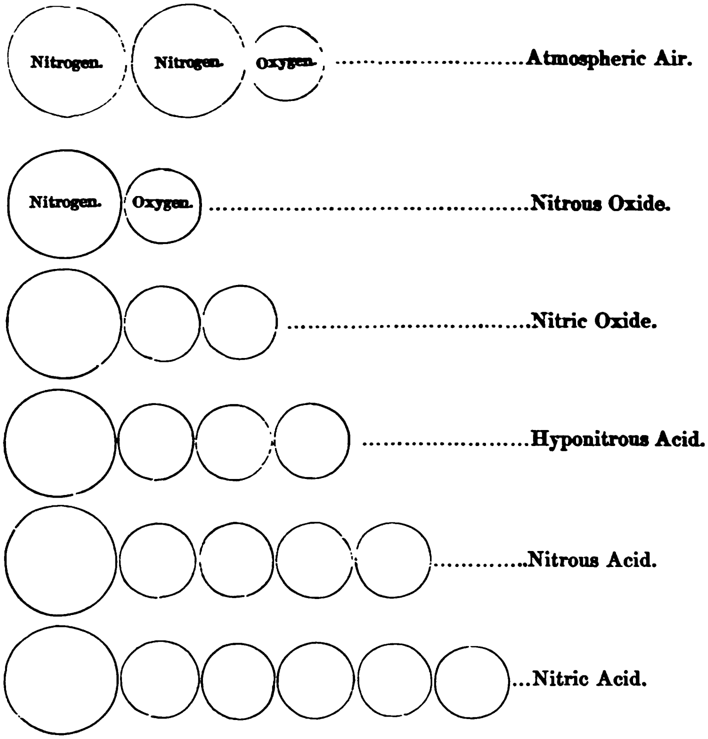
[*] " L'experience a demontré que, de meme que les élémens se combinent dans des proportions fixes et multiples, relativement a leur *poids*, ils se combinent aussi, d'une manière analogue, relativement à leur *volume*, lorsqu'ils sont à l'etat de gaz: en sorte qu' un volume d'un élément se combine, ou, avec un volume egal au sien, ou avec 2, 3, 4 et plus de fois son volume d'un autre element à l'etat de gaz. En comparant ensemble les phénomènes connus des combinaisons de substances gazeuses, nous découvrons les *memes lois* des proportions fixes, que celles que vous venons de deduire de leurs proportions *en poids:* ce qui donne lieu à une maniére de se representer les corps, qui doivent se combiner, sous des *volumes* relatifs à l'etat de gaz. Les degres de combinaisons sont absolument les mémes, et ce qui dans l'une est nommé *atome*, est dans l'autre apellé *volume.*"—*Berzelius*, Vol. iv., 549.

Or thus: Fig. 6.



A description of the properties of these distinct bodies may be found in any chemical work of authority, and I only mention these unions to exemplify the importance of attending to the *proportions* in which bodies unite ; as we here find the very elements of the air we breathe, by a mere change in the *proportions* in which they are united, forming so many distinct substances, from the *laughing gas*, nitrous oxide, up to that most powerful and destructive agent, *nitric acid*, commonly called *aqua-fortis.*

This case of the combination of nitrogen and oxygen also shows the importance of the distinction between *mechanical* and *chemical* union; these two elements being only *mechanically* united in forming *atmospheric air*, by which the essential properties of its two constituents are preserved unaltered; whereas, in the five bodies above enumerated, the union is *chemical*, and, consequently, the essential characters of their respective constituents are lost, and new ones obtained.

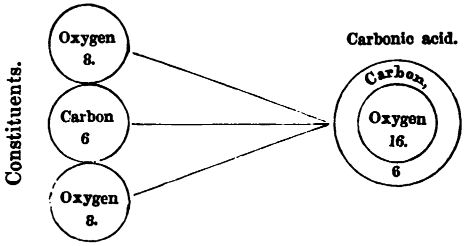
Now, to apply these principles to the bodies under consideration, namely, the *carbon* and *hydrogen*, and ascertain the proportions of oxygen they respectively require to produce chemical union.

These two constituents, though united in the one body—the gas, yet, not only separate themselves during combustion in a remarkable manner, but, *by two distinct processes*, *form two essentially different unions*. This is an important feature of the development of chemical action which the law of equivalents at once points out and enables us to satisfy, although this *double process* does not appear to be understood, much less to be provided for, *in practice*, though familiar to every chemist.

On the first application of heat, or, what may properly be termed, the firing or lighting the gas, when duly mixed with air, the carbon *separates itself from its fellow constituent*, *the hydrogen*, and forms an union with the former, the produce of which is *carbonic acid gas*.

Now, the laws of chemical proportion teach us, that carbonic acid is composed of *one atom* of carbon vapour, (by weight 6,) and *two atoms* of oxygen, (by weight 16,) the latter, in volume, being double that of the former, as in the annexed figure.

Fig. 7.



Thus, as far as the carbon is concerned, we obtain the information we sought, namely, its saturating equivalent of oxygen, and which we find to be just *double its own volume;* or, by weight, as 16 is to 6. But, without the aid of chemistry, we should here have remained satisfied; combustion would appear to have been complete; there would be no smoke, and no visible indication of an imperfect or unfinished process. Yet, chemistry tells us, we have only disposed of the *one* constituent of the gas, namely, the *carbon*, and that the *hydrogen, the second constituent*, remains yet to be accounted for, and converted to heating purposes.*

It is true, the carbon was, *in weight*, equal to six parts out of eight (the original weight of the gas.) *In bulk*, however, it was but one *fifth;* and when it is recollected, that, although the *illuminating* properties of the carbon are superior to those of the hydrogen, yet that the *heating* properties of the hydrogen are far superior to those of the carbon, we can appreciate the loss sustained, should these 4-5ths of the gas remain unconsumed.

To this may be added, the probable injury done to the heating powers of the flame by the conversion of any part of this otherwise valuable *hydrogen* into one of the most destructive compounds which can be met with in the furnace or flues, namely, *ammonia*, composed of unconsumed hydrogen and a portion of the nitrogen liberated from the air. Thus we have a double motive for providing against the escape, *unconsumed*, of the hydrogen of the gas.

What, then, is to be done? Let us complete this *second process* as we did the first: let us supply this hydrogen, this remaining 80 per cent. in volume, of the gas, with its own proper equivalent of oxygen, as we did in the case of the carbon.

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* I have here stated the case of the oxygen uniting with the *carbon*, before the *hydrogen*. Chemists are undecided on this point; and, indeed, the evidence at present is quite contradictory.

It is to be observed, however, that the argument, drawn from the combustion of the carbon before the hydrogen, or *vice versa*, is the same, as regards the point now under consideration. Whichever half passes off uncombined is lost.

But what is this second equivalent? By the same laws of definite proportions we learn, that the saturating equivalent of an atom, or any other given quantity of hydrogen, is, not *double* the volume, as in the case of the carbon, but *one-half* its volume only—the product being aqueous vapour, that is, *steam;* the relative weights of the combining volumes being 1 of hydrogen to 8 of oxygen; and the bulk, when combined, being two-thirds of the bulk of both taken together, as shown in the annexed figure 8.*

We thus find, that to saturate the *one* volume of carbon vapour, two volumes of oxygen are required; whereas to satu-

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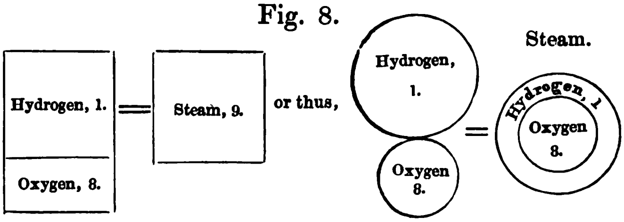
* Professor Brande puts this so clearly that I here give his own words:—"The simple ratio which the *weights* of the combining elements bear to each other involves an equally simple law in respect to combining *volumes*, where substances either exist, or may be supposed to exist, in the state of gas or vapour.

"Thus, water may be considered as a compound of 1 atom of hydrogen and 1 atom of oxygen, the relative weights of which are to each other as 1 to 8. Hence the *equivalent* of the atom of water will be, 1 hydrogen + 8 oxygen = 9. But oxygen and hydrogen exist in the gaseous state, and the weight of *equal volumes* of those gases (or, in other words, their relative densities, or specific gravities) are to each other as 1 to 16; hence 1 volume of hydrogen is combined with ½ a volume of oxygen to form 1 volume of the *vapour of water*, or *steam:* for the specific gravity of steam, compared with hydrogen, is as 1 to 9. The annexed diagram, therefore, will represent the combining *weights* and *volumes* of the elements of water and of its vapour."

Fig. 8.



The following is also much to the point:—"La composition de l'eau est un des élèmens les plus necessaires aux calculs des chemistes, les derniers experiences de rate the *two* volumes of hydrogen, *one* volume only of oxygen is required: thus,

FIRST CONSTITUENT.

Carbon.				Oxygen.						
Vol.	*Atom.*	*Weight.*		*Vol.*	*Atom.*	*Weight.*		*Vol.*	*Atom.*	*Weight.*
½	1	6	unite with	1	2	16	forming carbonic acid.	1	1	22

SECOND CONSTITUENT.

Hydrogen.				Oxygen.						
Vol.	*Atom.*	*Weight.*		*Vol.*	*Atom.*	*Weight.*		*Vol.*	*Atom.*	*Weight.*
2	2	2	unite with	1	2	16	forming steam	2	2	18

Here we see, that, in the case of this *first* constituent, as above, the *half* volume of carbon and *one* volume of oxygen become condensed into one volume of carbonic acid (as shown in figure 7); and that, in the *second* constituent, the *two* volumes (meaning double bulk) of hydrogen and *one* volume of oxygen become condensed into two volumes of steam (as shown in figure 8.)

No facts in chemistry, therefore, can be more decidedly proved, than that one atom of hydrogen and one atom of oxygen (*the former being double the bulk of the latter*) unite in the formation of water; and, further, that one atom of carbon vapour and two atoms of oxygen (*the latter being double the bulk of the former*) unite in the formation of carbonic acid gas.

Thus, the ultimate fact of which we were in search is, that the one condensed volume of the gas, as generated

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MM. Berzelius et Dulong out fourni pour sa composition des nombres qui sont adoptés par tous les chemistes. Elle est formée d'apres eux de

Oxygène	88·90	1 volume, oxygène.
Hydrogène	11·10	2 volumes, hydrogène.
	100·00	1 volume eau.

Parmi les nombreuses decouvertes que la science doit a M. Gay Lussac, on remarquera toujours la belle observation sur la composition de l'eau, qui le conduisit a trouver les vrais rapports des gaz et des vapeurs dans leurs combinaison. Des experiences tres exactes, qu'il avoit faites conjointement avec M. de Humbolt, lui prouverent *que l'eau etait formée d'un volume d'oxygène et de deux volumes de hydrogène*, resultat plainement confirmé depuis par tous les phenomènes ou l'eau joue un role actif, et qui s'accorde avec la composition trouvé par MM. Berzelius et Dulong."—*Dumas*, Vol. i., 33.

from the coal, requires two volumes, or *double its bulk of oxygen*, that being the quantity required for the saturation of its constituents *when separated.*

Now, this is the entire alphabet of the combustion of the carburetted hydrogen gas.

Having thus ascertained the quantity of *oxygen* required for the saturation and combustion of the two constituents of coal gas, the only remaining point to be decided is, *the quantity of air that will be required to supply this quantity of oxygen.*

This is easily ascertained, seeing that we know precisely the proportion which oxygen bears, in volume, to that of the air. For, as the oxygen is but *one-fifth* of the bulk of the air, *five* volumes of the latter will necessarily be required to produce *one* of the former; and, as we want *two* volumes of oxygen for each volume of the coal gas, it follows, that, *to obtain those two volumes, we must provide ten volumes of air.*

Thus, then, by strict chemical proof, we have obtained these facts:—First, that each volume of coal gas requires two volumes of oxygen; secondly, that to obtain these two volumes of oxygen we must employ eight atoms of air; thirdly, that these eight atoms of air are equal to ten volumes of the coal gas; each volume of the latter, in fact, requiring ten volumes, or *ten times its bulk* of air: thus,

Ten *volumes* of air are the same as eight *atoms;*
Eight atoms of air produce four atoms of oxygen;
Four atoms of oxygen are equal to two volumes of the same; and
Two volumes of oxygen saturate one volume of the coal gas:
Therefore, *ten* volumes of air are required for each *one* volume of this gas.

We now see why *ten* volumes of air are required for each volume of gas, and why *neither more nor less* will satisfy the conditions of its combustion. For, if *more*, the excess, independently of the mischievous chemical unions it might enter into in the furnace, wouldbe the means of carrying away as much heat as it would take up by its expanding faculty. And if *less*, a corresponding quantity of either hydrogen or carbon would be deficient of its *supporter*, and necessarily pass off uncombined and unconsumed.

The difficulty of keeping in mind these complex relations of the gases, with their relative volumes, number of atoms, and states of condensation and expansion, present great obstacles in the way of those who have not attended to the subject. To assist the unlearned in this matter and aid the memory, and with the view of bringing these facts under the eye in a condensed form, I have prepared the diagram or tabulated view, (No. 1,) of these several processes, and, especially, of *the order* in which they come into operation ; a circumstance which is wholly overlooked in practice, but on which, as I shall hereafter show, depends the circumstances of perfect or imperfect combustion.

As the proportion of air required for the combustion of the *bi-carburretted* hydrogen (olefiant gas) is necessarily larger than what is required for the *carburetted* hydrogen, I have also added a diagram of the former, (No. 2,) on the same plan, and showing the volume of air required for its combustion.

The only observation here necessary to make on the difference between these two gases is, that, as this latter gas contains *two* atoms of carbon instead of *one*, it follows that a proportionate additional quantity of oxygen will be required for this additional atom of carbon. Hence, if carburetted hydrogen requires *two* volumes of oxygen for combustion, the bi-carburetted hydrogen will require *three* volumes. And so of air: if ten volumes of air are required for the one gas, fifteen volumes are, consequently, required for the other gas. This will be seen by reference to the second diagram.

I conclude this part of the subject in the words of my talented and esteemed friend, Professor Brande, when treating of the same matter. " My object here has been to divest the subject of all hypothetical difficulty, and to present it to the student as involving a series of important practical applications, and as founded on the basis of experiment."

It is also observed by that able practical chemist, Dr. Reid, of Edinburgh, in his Elements:—"Since the existence of chemistry, as a science, no principle is pointed out so broadly connected with the whole range of its investigations as the laws of combination in definite proportions. It embraces not only some of the most brilliant discoveries, but also many of the *most useful practical applications* of the science, and has enabled the accumulated mass of facts, which it now embraces, to be reduced to a comparatively *systematic law*."

OBSERVATIONS EXPLANATORY OF THE DIAGRAMS REPRESENTING THE COMBUSTION OF CARBURETTED AND BI-CARBURETTED HYDROGEN.

First, of the carburetted hydrogen, diagram No. 1.

The following observations will enable the reader more adequately to appreciate the effect of the several changes which occur during the complicated process of combustion of coal gas, as shown in this diagram. They will also assist him in recollecting the relations, as to *quantities*, between the several bodies which unite during that process, and the *compounds* which such quantities relatively produce.

In the *first column, to the left*, are represented the elementary constituents of a single atom (and, proportionally, of any larger quantity) of the mixed gas, *carburetted hydrogen;* and below it, in the same column, those of *four* atoms of atmospheric air, which we shall see is the "*equivalent*" required for its saturation and combustion. This column presents us with an aggregate of *fifteen* separate atoms, thus :

Coal Gas............	1 atom of Carbon Vapour, 2 atoms of Hydrogen,	both combustible.
Atmospheric Air	4 atoms of Oxygen :	a supporter of combustion.
	8 atoms of Nitrogen :	neither combustible nor a supporter of combustion.
Total	15 atoms	

We see, (by this first column,) that the coal gas is compounded of *two atoms of hydrogen and one atom of carbon vapour*, which, for brevity sake, may be called *carbon*. This elementary constitution of the gas should be kept in mind while examining the succeeding changes; since each of these *three* atoms, during combustion, will be found to take its own road, and form its own particular union and product.*

The *second* column represents these constituents in their combined states of gas and air.

The *third* column represents the mixing or mere *bringing together* of the five compound atoms from column *two*.

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* The explanation of the symbols employed (as given at the foot of the diagram) will show the relative size and weight of each simple or compound atom—*hydrogen* being taken as *unity* for both purposes. These relative proportions are in conformity with what is laid down by the first British chemists of the day. Berzelius, and the continental chemists after him, have taken *oxygen* as unity. The reasons stated by Mr. Brande, in his Manual of Chemistry, appear sufficiently strong in favour of the practice among British chemists.

In contriving these symbols, I have given to each a colour most analogous to our conception of the bodies they represent, viz., carbon, black, as indicating charcoal; oxygen, red, the best representative of fire, of which it is the direct source; nitrogen, blue, as indicative of atmospheric air, of which it forms so large a portion as four-fifths. Hydrogen I had at first represented green, from its corresponding with the colour which is usually given to sea water, of which hydrogen forms the largest part. Green, however, being undistinguishable from blue by candle light, I have substituted *brown*.

This peculiar kind of mixing, technically called "*diffusion*", is effected by the influence of some hitherto unknown faculty which is peculiar to all gaseous bodies ; as by it, and contrary to the laws of gravity, those several atoms are brought within their respective spheres or range of mutual chemical action.

This contiguity of atoms, therefore, is an essential preparative. It is, in fact, the *sine qua non* of subsequent union—each of the three atoms of the *combustible* being thus in a position favourable for chemical action and union with its respective equivalent of the "*supporter*" whenever they shall be urged to such action by increased temperature.

All being so arranged, this is the state of things and the time favourable for ignition and combustion. On the necessary heat being applied, new changes take place throughout the whole. All the atoms become expanded ; their respective and relative forces of adhesion or attraction changed, and a new arrangement takes place, as represented in the next column.

Column *four* represents this new state of things, which is, in fact, the *first* process or stage of *actual combustion ;* and which is effected by the *decomposition*, the *breaking up*, or *separation* of the elementary constitutents, both of the gas and the air, and bringing them to the state exhibited in column *one*. By this separation, each is enabled to enter into new engagements, and attach itself to such portion or portions of the supporter—the *oxygen*, as its peculiar nature and force of affinity qualify it to adopt.

Here we perceive, (column 4,) that the relative quantities of gas and air are in exact *saturating proportions :* each of the three atoms of the *combustible* taking its proper place, on being supplied with its due proportion of the *supporter*, preparatory to that chemical union and condensation by which the new classes of bodies—the products of their combustion are produced; the *incombustible* nitrogen alone remaining unattached.

Column *five* represents the results or *products* of these unions, namely, one atom of carbonic acid from the combustion of the *one* atom of carbon; and two atoms of aqueous vapour, or steam, from the combustion of the *two* atoms of hydrogen; the great mass of nitrogen (eight atoms) passing away uncombined.

In observing this curious arrangement by which the saturation of *all* the combustible atoms is effected, we perceive, that the *three* atoms of the combustible are apportioned among *four* of the supporter. This, we see, is the result of the *one* atom of carbon requiring *two* of the supporter, while the two of hydrogen are satisfied with *one* each.

Now, in this arrangement, no *excess* or *deficiency* appears among the *useful*—the heat-producing ingredients. Could we have dispensed with, or avoided the presence of, such an excess of *nitrogen*, (which is neither a combustible nor a supporter of combustion, but, on the contrary, a mischievous intruder,) the several unions would have been less embarrassed—their combustion more rapid and complete—and the intensity of their action much increased. That, however, was impossible, the presence of so large a quantity of nitrogen being the unavoidable condition of obtaining the oxygen through the instrumentality of atmospheric air.

It is here to be observed, that the process of combustion, as thus described, is the most perfect that could be produced either in a furnace or a lamp: any deviation, therefore, by means of excess or deficiency, or from any interruption or interference, such as the interposition of another gas, must be more or less destructive of the desired effect, namely, the generation of the greatest quantity of available heat.

The first impression, on looking at this diagram, is that caused by the preponderating quantity of the colour, blue, representing the useless nitrogen. Hence we see the danger of forcing it into union with either of the combustibles. On this head we need have no apprehension, if the necessary *quantity of air be supplied, and the preparatory mixture, or diffusion, be duly effected; both of which are equally essential to entire combustion.* If these conditions be complied with, the stronger affinity which carbon and hydrogen have for oxygen, will always secure to the latter a preference.

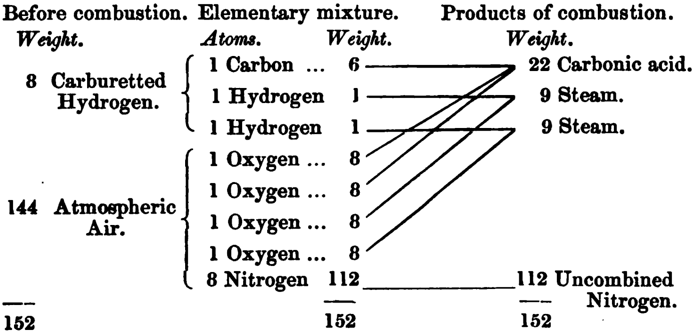
But, let us suppose the case of a *deficiency* of air by the supply being short of what chemistry has shown is the saturating quantity. In that case, should any portion either of carbon or hydrogen, from the want of oxygen, combine with nitrogen, (which, we see, must always be in excess,) we should only be exchanging a valuable *heat-giving* union, for an injurious *heat-absorbing* one: carbon forming *cyanogen*, and hydrogen forming *ammonia*, by their unions with the disengaged nitrogen.

The next impression which an inspection of the diagram produces is, that it presents to our view the exact proportions of air and oxygen required. This is strikingly exhibited in column *four*, where we see each atom of the combustibles and the supporter has its precise duty alloted to it, and that if, on the one hand, there were any *deficiency* of oxygen, one or other of the atoms of the combustible *being left without a supporter*, must necessarily pass away uncombined and unconsumed; so, on the other hand, if there were any *excess*, it could be of no service as a *heat-giving* body, from *the want of a combustible* with which to unite; but would become positively injurious by its cooling influence and the quantity of latent heat it would carry out of the furnace.

In observing column *three*, we cannot avoid being struck with the disproportion between the *largeness* of the required volume of *air* comparatively with the *smallness* of the volume of *gas* with which it is to unite and be consumed. This also suggests the difficulty of introducing so large a mass of air to the *gas*, without the risk of injuriously reducing its temperature below the point of accension, or kindling. This, in fact, is the main difficulty which we encounter when burning coal on the large scale in the furnace.

We see, however, that *neither more nor less*, even to that of a single atom, can satisfy the condition of *entire combustion* of the gaseous portion alone of the coal; and that it is only suffering ourselves to be deceived by appearances, if, from the absence of any *visible* black smoke, we imagine we have effected entire combustion, while any deficiency exists in the supply of air.

To this may be added a diagram, after the mode adopted by Professor Brande and others, and which so clearly indicates the relative *weights* of the atoms employed both before and after combustion.



Secondly, of the *bi-carburetted* hydrogen, or olefiant gas, diagram No. 2.

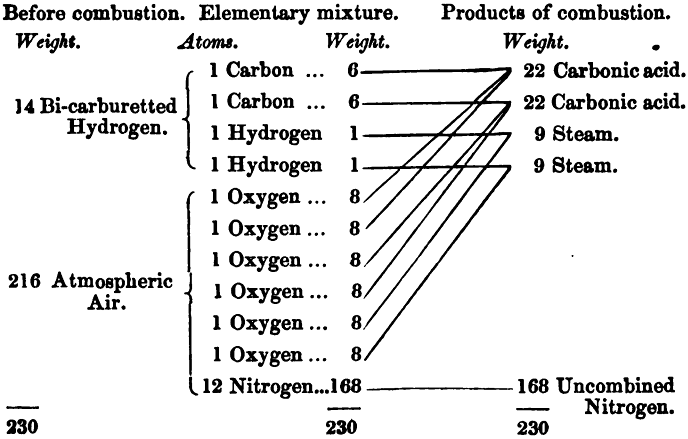
The preceding observations are all equally applicable to the diagram representing the combustion of this gas, bi-carburetted hydrogen, a portion of which is always found to exist in ordinary coal gas.

In this diagram the preponderating quantity of *nitrogen* (blue) is still more apparent, inasmuch as the quantity of air required for the combustion of *bi-carburetted* hydrogen is *fifteen* times the volume of the gas to be consumed, instead of *ten*, as in the combustion of *carburetted* hydrogen; the whole of the difference between these two species of inflammable gas arising out of the addition of a *single atom* or proportion of *carbon*, as will be seen by an inspection of the first column in both diagrams.

In the first column are given the elementary constituents of an atom of this gas and six atoms of air, that being the equivalent required for its saturation and combustion. In the former diagram we had an aggregate of 15 atoms: in this we have 22 atoms: namely,

1 atom of the gas	2 atoms of carbon vapour 2 atoms of hydrogen	both combustible.
6 atoms of air ...	6 atoms of oxygen	the supporter of combustion.
	12 atoms of nitrogen	neither combustible nor supporter of combustion.
	22	

To this may also be added a diagram corresponding with that of the carburetted hydrogen: thus,



Before combustion. *Weight.*	Elementary mixture. *Atoms.*	*Weight.*	Products of combustion. *Weight.*
	1 Carbon ...	6	22 Carbonic acid.
14 Bi-carburetted Hydrogen.	1 Carbon ...	6	22 Carbonic acid.
	1 Hydrogen	1	9 Steam.
	1 Hydrogen	1	9 Steam.
	1 Oxygen ...	8	
	1 Oxygen ...	8	
	1 Oxygen ...	8	
216 Atmospheric Air.	1 Oxygen ...	8	
	1 Oxygen ...	8	
	1 Oxygen ...	8	
	12 Nitrogen...	168	168 Uncombined Nitrogen.
230		230	230

SECTION IV.

OF THE QUANTITY OF AIR REQUIRED FOR THE COMBUSTION OF CARBON AFTER THE GAS HAS BEEN GENERATED.

HAVING disposed of the question of quantity, as regards the supply of air required for the saturation and combustion of the bituminous, or gaseous portion of coal, we have now to answer a corresponding question, with reference to the carbonaceous part resting in a solid form on the bars of the furnace, and assuming a red, glowing appearance, *after* the gaseous matter has been evolved.

We have seen, that, in the formation of the carburetted hydrogen, a considerable portion of the carbonaceous constituent of coal has been separated and carried away by the hydrogen in the *gaseous form*, forming the carburetted hydrogen: the *remainder* of such carbonaceous matter is what we have now to deal with; the difference, as regards combustion, between these two portions of carbon being so important as to demand a special notice.

On the gases being expelled from coal, in the *retorts* of gas-making establishments, the solid portion which remains is called *coke*. With reference, however, to its condition *in the furnace*, (and in which condition we are now considering its union with oxygen,) I know not what to call it; no distinctive term having been applied to it. This can only be accounted for by the fact, that this natural, indispensable division of the process of the combustion of coals in the furnace has not been sufficiently identified or described by scientific men.

Now, what is this substance for which a distinctive name would be desirable, as well for the sake of perspicuity as brevity, when speaking of its properties and the peculiarities with which it enters into combustion? It is not coal, nor coke, nor cinders, nor carbon; yet it partakes of many of the properties of each, although it differs from them all.

That for which I am desirous of having a distinctive appellation is the portion of the carbonaceous constituent of the coal which remains on the bars of a furnace after the coal has given off its volatilizable part, and while it retains its red, glowing, or incandescent character, and is ready to enter into combustion.

This solid matter, which, in the absence of a more precise term, I will call *carbon*, as involving its leading characteristic, is stated, by chemists, to be susceptible of uniting with oxygen in three proportions, by which three distinct bodies are formed, possessing distinct chemical properties.

This peculiarity of the unions of carbon with oxygen is wholly unattended to in practice: yet we shall see how essential it is in considering the quantity of air to be introduced to a furnace.

These three proportions, in which carbon unites with oxygen, form, first, *carbonic acid;* second, *carbonic oxide;* and, third, *carbonous acid* (or oxalic acid.) With the first and second only we have to deal in the *furnace*, and I will, therefore, confine my observations to them.

In the first, the carbon unites with two volumes of oxygen, forming carbonic *acid;* and, in the second, with one volume, forming carbonic *oxide.* The difference between these two formations is peculiarly important to our present subject.

With respect to the first, and the quantity of air required for its formation, this may be said to have been already disposed of when treating of the carbonaceous constituent of the *gas.* It is true, *that* constituent of coal was in a *gaseous* state, whereas what we have now to treat of is in a *solid* state: as regards the quantity of air, however, this creates no difference, as the latter must still undergo the process of vaporization in the act of combustion, for it is only in the state of vapour that it unites with oxygen and that we can estimate its equivalent of air.*

Whatever weight of *solid* carbon, therefore, produces a given quantity of *gaseous* carbon, in carburetted hydrogen, (estimated by the quantity of oxygen it requires to form carbonic acid,) must, necessarily, do the same in the case of the solid carbon on the bars, of which we are now speaking. Two volumes of oxygen (or five volumes of air) are, therefore, the saturating equivalent of each volume of carbon vapour, as already shown; whether such carbon has been vapourized among the constituents of the gas, or *directly* from the solid carbon on the bars.

Were carbonic acid the only product of the combustion of the carbon of the coals in the furnace, no more would here have to be said; but there is the other state in which we find carbon uniting and passing away with oxygen, and which gives rise to considerations of the utmost importance in this branch of the inquiry. This other state is that of carbonic *oxide*, the formation of which, in the furnace, is wholly unheeded in practice, although its influence on the quantity of heat obtained is very considerable.

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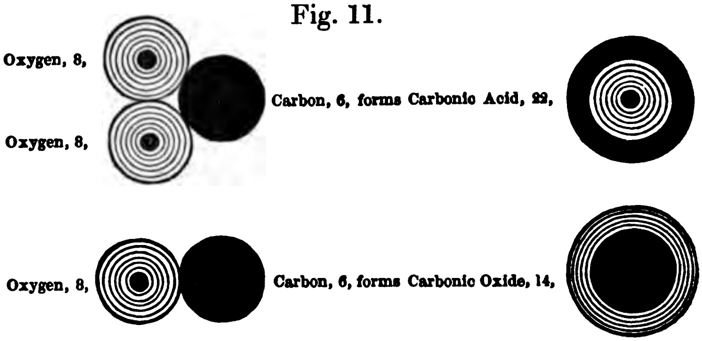
* "Carbon has never, in its elementary state, been raised in vapour; but, nevertheless, in such of its compounds as assume the gaseous state, its constituent particles must have a gaseous arrangement."—*Daniell's Chemical Philosophy.*

Carbonic *acid*, we have seen, is a compound of one atom of carbon with two atoms of oxygen; while carbonic *oxide* is composed of the same quantity of carbon with but *half* the above quantity of oxygen, as in the annexed figure:

Fig. 11.


Oxygen, 8,
Oxygen, 8,
Carbon, 6, forms Carbonic Acid, 22,
Oxygen, 8,
Carbon, 6, forms Carbonic Oxide, 14,

Here we see, that carbonic *oxide*, though containing but one-half the quantity of oxygen, is yet of the same bulk or volume as carbonic *acid*, a circumstance of considerable importance on the mere question of *draught*, as will be hereafter shown.

The quantity of oxygen thus required to form carbonic oxide, being but one-half what has been shown as its *saturating* equivalent, as we see in carbonic acid, the consequence is, that this carbonic oxide becomes a *combustible*, rather than a *product of combustion*, and which is the fact.

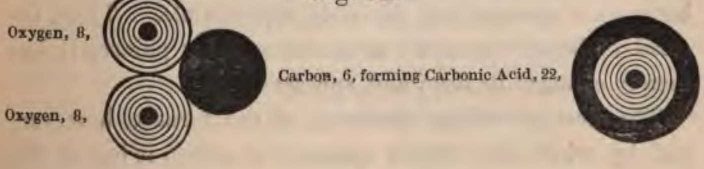
If, then, we require the full measure of heat from the combustion of carbonic oxide, we have no alternative but to fill up the measure of oxygen, by providing, and uniting with it, the other half, so that the product shall be carbonic *acid*. If this be not effected, it is clear the carbon is but *half burned*, for it has united with but half the quantity of oxygen which is essential to full combustion.

Now, this combustion of the oxide, by its conversion into the acid, is as distinct an operation as the combustion of the carburetted hydrogen, or any other combustible, and demands all the preparatory conditions in the furnace that the latter does; namely, providing it with a due supply of oxygen, in due mixture, temperature, &c., yet all this is wholly overlooked *in practice* in the operations carried on in the furnace.

But the most important view of the question, and one which is little known to practitioners outside the laboratory, is as regards the *formation* of this carbonic *oxide:* why it exists in the furnace? what brought it there? and how is this combustible generated from an incombustible? And this is the part of the inquiry which most requires our attention.

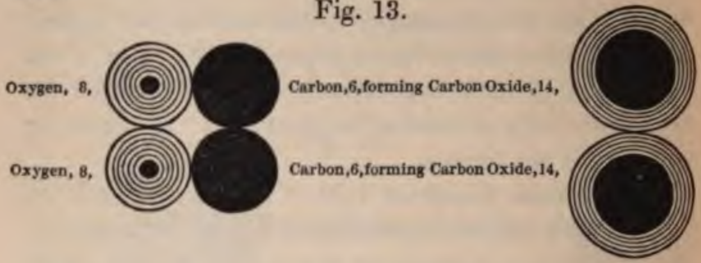
The first and *direct* effect of the combustion of carbon and oxygen is the formation of carbonic *acid*, by their union *in saturating proportions;* namely, two atoms, or volumes, of oxygen with one of carbon vapour. If, however, by any means, we *abstract* one of its portions of *oxygen*, the remaining proportions would then be those of carbonic *oxide*. But this we cannot effect in the furnace. It is equally clear, however, that if we *add* a second portion of *carbon* to carbonic *acid*, we shall arrive at the same result, namely, the having carbon and oxygen combined in equal proportions, as we see in carbonic *oxide*. Now, this is, in fact, what takes place in the furnace, and this is the mode in which this *combustible* is formed—thus :

Fig. 12.



By the addition, then, of a *second* proportion of carbon to the above, *two* volumes of carbonic *oxide* will be formed—thus:

Fig. 13.


Oxygen, 8,
Carbon,6,forming Carbon Oxide,14,
Oxygen, 8,
Carbon,6,forming Carbon Oxide,14,

Here we see the addition of *one* atom of carbon has had the effect of *doubling* the bulk of the resulting compound by the formation of *two* volumes of carbonic oxide, for, as already observed, the bulk of carbonic oxide is the same as that of carbonic acid.

Now, if these two volumes of carbonic oxide, once formed in the furnace, cannot find the portion of oxygen required to complete their *saturating* equivalent, they pass away necessarily but *half consumed*, a circumstance which is constantly taking place in all furnaces where the air has to pass through a large body of incandescent carbonaceous matter.

This, also, frequently leads to a fatal error in what is called the "combustion of smoke": for if, after the separation of the carbonaceous constituent of coal, and while yet at a high temperature, it encounters carbonic *acid*, this latter, taking up an additional portion of carbon, is converted into carbonic *oxide*, as shown in the last example, and again becomes a gaseous and invisible combustible. Thus, instead of being "burned", as is the ordinary phrase, it has merely changed its form and appearance.

The most prevailing operation of the furnace, however, and by which the largest quantity of carbon is lost in the shape of carbonic *oxide*, is thus :—The air, on entering from the ashpit, gives out its oxygen to the glowing carbon on the bars, and generates much heat in the formation of carbonic acid. This *acid*, necessarily at a very high temperature, passing upwards through the body of incandescent, solid matter, takes up an additional portion of the carbon, and becomes carbonic *oxide*. In this state it is equally a claimant on the admitted air, as well as the coal-gas, for its equivalent of oxygen; and, in default of which, one or both pass away, as before mentioned, uncombined and unconsumed.*

Thus, by the conversion of one volume of *acid* into two volumes of *oxide*, heat is actually absorbed, while we also lose the portion of carbon taken up during such conversion, and are deceived by imagining we have " *burned the smoke*."

The formation of this compound, carbonic oxide, being thus attended by circumstances of a curious and involved nature, is, probably, the cause of the prevailing ignorance of its properties among unscientific men and their inattention to its effects. For, while we find, in every mouth, the term *carbonic acid*, as the product of combustion, we hear little of *carbonic oxide*, one of the most waste-inducing compounds of the furnace, unless provided with its equivalent volume of air, by which its combustion will be effected.

Under any circumstances, then, by reason of the proportion of carbon to oxygen in the oxide not being the *saturating one*, we have not the full measure of heat from their union. It is, in fact, a defective union of carbon and oxygen, as regards combustibility, and our object should be to prevent its formation.*

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* "Carbonic oxide may be obtained by transmitting carbonic acid over red-hot fragments of charcoal contained in an iron or porcelain tube. It is easily kindled: combines with half its volume of oxygen, forming carbonic acid, which retains the original volume of the carbonic oxide. The combustion is often witnessed in a coke or charcoal fire. The carbonic acid produced in the lower part of the fire is converted into carbonic oxide as it passes up through the red-hot embers."—*Graham's Elements of Chemistry*.

Whatever tends to bring carbon, while at a high temperature, into contact with carbonic *acid*, tends to the formation of carbonic *oxide* and the reconversion of an incombustible into a combustible gas, at the expense of the portion of carbon which we see is the element of its conversion, and which becomes a *pro tanto* loss, unless subsequently supplied with an additional volume of oxygen whereby to effect its reconversion and combustion ; but which, under the irregular conditions of a furnace, can scarcely be expected.

Another important peculiarity of this gas (carbonic oxide) is, that, by reason of its already possessing *one-half* its equivalent of oxygen, it inflames at a lower temperature than the ordinary *coal-gas ;* the consequence of which is, that the *latter*, on passing into the flues, is often cooled down below the temperature of accension; while the *former* is sufficiently heated, even after having reached the top of the chimney, and is there ignited on meeting the air. This is the cause of the red flame which we see at the tops of chimneys and the funnels of steam-vessels.

We may thus set it down as a certainty, that, if the carbon, either of the gas or of the solid mass on the bars, passes away in union with oxygen, in any other form or proportion than that of *carbonic acid*, a commensurate loss of heating effect is the result.

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* "Among the stove-doctors of the present day, none are more dangerous than those who, on pretence of economy and convenience, recommend to keep a large body of coke burning slowly, with a slow circulation of air. An acquaintance with chemical science would teach them, that, in the obscure combustion of coke or charcoal, much carbonic oxide is generated, and much fuel consumed, with the production of little heat; and physical science would teach them, that, when the chimney draught is languid, the burned air is apt to regurgitate through every seam or crevice, with the imminent risk of causing asphyxia, or death to the inmates of apartments so preposterously heated."—*Dr. Ure's Paper on Ventilating and Heating Apartments, read before the Royal Society, 16th June*, 1836.

Hence, we see how the peculiar influence which carbonic *oxide* exercises, in its formation and combustion, justifies the observation of Chevreul, in his "Leçons de Chimie", that "*la connoissance de ses propriétés est indispensable pour bien connoitre le carbon.*" And here we are let into the secret of those deceptive results which have led so many patentees astray, who, under the idea of "burning the smoke", have exercised their ingenuity in the mere production of carbonic oxide; and, because no black smoke was visible at the chimney shaft, deceived themselves and others under the impression that it had been consumed. Here, also, we see how essential is chemical investigation; for how should we be enabled to form any other conclusion, on perceiving the absence of smoke, than that it was absolutely burned, and a proportionably increased quantity of heat generated; instead of the fact, which chemistry alone could teach us, that not carbonic acid, but carbonic oxide was formed—heat absorbed—and a valuable portion of the carbon irretrievably lost?

SECTION V.

OF THE QUALITY OF THE AIR ADMITTED TO A FURNACE.

When we speak of mixing a given quantity of oxygen with a given quantity of coal gas, we do so because we know that such quantity of the former is required to saturate the latter; and that, by such saturation, every atom of *both* gases enters into union, without excess or deficiency of either, producing entire, complete combustion.

So when we speak of mixing a given volume of atmospheric air with a given volume of coal-gas, we do so for the same purpose, knowing that such precise quantity of *air* will provide the required quantity of *oxygen*.

Thus, if we know that *two* cubic feet of oxygen are the exact saturating equivalent, or combining volume, for effecting the entire combustion of *one* cubic foot of coal-gas, we know that ten cubic feet of atmospheric air will effect the same purpose, because ten cubic feet of air contain the required two cubic feet of oxygen.

It is manifest, therefore, that, when we direct any given portion of air to be employed, we do so on the presumption, that it contains its due complement of oxygen, and that it is, in fact, pure, unadulterated atmospheric air.

If, however, by any circumstance, accidental or otherwise, the air we employ has either lost any portion of its oxygen, or is mixed with any other gas or matter, it no longer bears the character of pure atmospheric air, and is no longer capable of producing the same effect. It is, in fact, *not the thing we directed to be employed*, and cannot satisfy the condition as to *quantity* of *oxygen*, which was essential to our purpose. For it must be borne in mind, that, in all chemical processes, (of which combustion is one,) an excess or deficiency of any of the bodies to be employed is not to be treated as a matter of indifference, but that, in a greater or lesser degree, will it mar the precise results expected.

So in the case under consideration.

We require *ten* cubic feet of air to supply *two* cubic feet of oxygen to effect the combustion of *one* cubic foot of coal gas; but, if this quantity of air does not contain this 20 per cent., or 1-5th of oxygen, it is manifest we cannot obtain it. The air, in this case, may be said to be vitiated or deteriorated; and in this sense the *quality* of the air we employ is entitled to serious consideration.

The question, then, of complete, entire combustion is one mainly dependant on the quantity of oxygen to be obtained from any given volume of air. Hence, the necessary inquiry into the purity or *quality* of the air we employ, and whether it contains its due 1-5th of oxygen. For, if the oxygen be not in the air, how can it otherwise be obtained? How can we effect a union with a thing which is not?

Let us now inquire how far the ordinary mode of constructing and managing our furnaces enables us to satisfy this condition, namely, the providing *pure*, *undeteriorated*, *unvitiated air* both to the solid, *carbonaceous* portion of the coal on the bars, and the *gaseous* portion in the body of the furnace.

In ordinary practice, the supply of air to the furnace is by means of the *ashpit;* and, with the view of giving *enough*, the ashpit entrance is directed to be made large, it being usually the full breadth of the furnace, and of a depth from 3 to 5 feet. This enlarged size is given under the mistaken notion, that the more air we give, the better will be the draught—the more complete the combustion—and the greater the quantity of heat produced.*

In this case we see the introduction of *air* is considered tantamount to the introduction of *oxygen;* and it might, with safety, be so considered, if there were but *one* description of combustible to be used. But here lies the main point. We have *two* distinct kinds, and in two distinct states and places; each requiring a distinct management, and a specific quantity of air, to effect its separate process of combustion. These two processes are, as already described, first, the combustion of the *gas* generated in the body of the furnace, and passing off by the flues; and, second, the combustion of the *solid carbon* resting on the bars.

Tredgold, and most others after him, overlooking these distinctive features in the processes which *coal* undergoes in its progress towards combustion, gives preposterous directions as to the introduction of air. He says, "The opening to admit air (the ashpit) should be sufficiently large for producing the greatest quantity of steam that can be required, but not larger." Here we find the "*quantity of steam*" actually considered as dependant on the area of "the *opening to admit air*" to the ashpit, than which nothing can be more incorrect. In showing the importance of a "free access of air to every part of *the fuel*", he observes, that "the area of the spaces *between the bars* should clearly be greater than the area of the place that *admits air to the fire*", still overlooking the distinction between the combustion of the gas at the bridge and the carbon on the bars, with the peculiar and distinct conditions under which these two separate processes are to be carried on.

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* "A quantity of air," says Tredgold, "sufficient to supply oxygen for combustion, must have *as free access as possible to all parts of the burning mass*"; and then he comes to the conclusion, "But abundance of air will pass the grate if it be properly constructed, and the modification I would recommend is described in plate second." On examining this plate I find it has no provision whatever for the introduction of air beyond the ordinary plan of a *large open ashpit*. Nothing can be further from a sound, judicious plan of introducing air than those "*practical rules*" of Tredgold.

Here we have this high authority, whose books are in every one's hands, and received as standards, insisting on a large ashpit, *free access* of the air *to the fuel* on the bars, (without any allusion to the gaseous products,) and an ample allowance of space between the bars for the admission of air, and on the assumed principle, that such space is to regulate the *quantity of steam* obtained. All of this is utterly at variance with chemical propriety, and the reverse of what judicious management would require.

That Tredgold did not consider this point as one of trivial importance is manifest from the introductory paragraph to his chapter on "fire-places",* and I do not quote him for the purpose of any contrast between a correct view of the "operation of burning" and that which he exhibits, but to show, that, if such a man could so palpably overlook the *chemical* essentials in the combustion of the two separate constituents of coal, it cannot be a matter of surprise that mechanics, who have been taught to follow in his steps and adopt his laws, should have made so little advance in perfecting our system of furnaces.

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* "In the construction of fire-places for boilers," he observes, "we have to combine every thing which is likely to add to the effect of fuel, and to avoid every thing which tends to diminish it, as far as possible. Now, without some knowledge of the nature of the operation of burning, it will scarcely be possible to do any thing good *except by mere accident*. We should be like seamen in a vessel at sea without a compass, with as little chance of steering to the intended port."

No one can question whether the absence of a compass would not be preferable to one which should directly induce us to steer a wrong course.

I have alluded to Tredgold's directions with the view of pointing attention to that which has hitherto been so neglected, namely, the two distinct operations of supplying air to the *gas* generated in the upper part of the furnace, and to the solid *carbon* resting on the bars; and, also, to the injury caused by compelling the *whole supply* to pass through the ashpit, and through such solid carbon; by which not only a deficiency of oxygen is occasioned in the air intended for burning the gas, but an undue and injurious urging of the combustion of the carbonaceous matter, and the consequent melting of the bars and destruction of the furnace-plates of marine boilers.*

Indeed, all that seems to be concluded in practice is, that oxygen is essential to combustion;—that providing a sufficiency of *air* is providing a sufficiency of *oxygen*;—and that, if air be admitted to "*the fuel*", it will do its duty and work out the process of combustion satisfactorily, in its own way. Hence the great neglect of the *chemical* conditions of combustion, and the many errors and absurdities of the present practice.

For can there be a more absurd practice than is involved in this single position, namely, that while a given quantity of *pure* air is required for the combustion of the *coal-gas* generated in the furnace, we compel that air, in the first instance, to pass through the bars and body of solid incandescent combustible matter resting upon them, by which it is necessarily deteriorated in *quality* from the loss of much, if not the whole, of that oxygen for which alone the air is employed, and still expect *perfect*, full combustion of the gaseous matter, contrary to all chemical experience, from such vitiated air.*

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* "To succeed in consuming the combustible gases," observe Tredgold, "it is necessary that they mix with air that has become hot, by passing *through*, *over*, *or among the fuel which has ceased to smoke*: the words of the patent of Mr. Watt, dated 1785."

Here there can be no mistake, yet nothing can be more unscientific or unsound in principle. The inevitable result of this operation would be, first, the depriving the air, more or less, of its oxygen; and, second, by urging this increased quantity of air to act like a blast on such red-hot fuel, to consume it with unnecessary and injurious rapidity.

In illustration of this, let us suppose, that 100 represents the quantity of air required per minute for the perfect combustion of the gaseous products at the bridge; and that 200 represents the quantity required for the use of the carbon on the bars. Let us farther suppose, that, instead of sending each of those quantities *separately* to perform its respective duty, by giving up its constituent oxygen to its proper combustible, (and for which express duty it was employed,) we sent the *entire* of both quantities, say 300, through such burning mass of solid carbon; can we doubt that the result would be, first, the impelling this latter to an increased and undue action; and, secondly, the vitiating the air intended for the gaseous combustibles, by depriving it of its due proportion of oxygen.

For what is this increased action of the carbon on the bars but increased combustion? and what is this but an increased absorption of oxygen, the very oxygen which had been intended for a different purpose? This cannot be denied, neither will it, that the direct result is to deteriorate the *quality* of the 100 measures of air thus sent by an improper route to the gaseous constituent of the coal.

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* Mr. Parkes has clearly pointed out the injury caused by allowing the air to be thus "vitiated." He observes, "I frequently found the smoke increased by the admission of the air, and observed the pressure of steam to fall in consequence. I was perplexed, but the study of Davy, at length, furnished me with the clue for extricating myself from the labyrinth. I perceived that the conditions upon which success depended were not fulfilled, and that failure was unavoidable: that the air must be given *directly to the uninflamed gas; whereas it had become vitiated by passing over the inflamed fuel*."—*Transactions of Civil Engineers*, vol. ii., p. 62.

This is the main cause of the air being vitiated; yet, as I shall abundantly show hereafter, many patents continue to be taken out expressly for effecting this very purpose, which Mr. Parkes practically demonstrated was leading to "unavoidable failure." Indeed, I have found, in Mr. Parkes' tracts, published nearly twenty years ago, the first indications of the true principles on which effective combustion can be effected *in a furnace*.

Let us suppose another case, one of laboratory practice; that of ascertaining the largest quantity of carbonic acid and water that could be produced from any given quantity of coal-gas and air, for this is, in fact, what we desire to effect in the furnace.

After adjusting our apparatus, and measuring the proportions of gas to be operated on, and air to be mixed with it, suppose we should discover that the latter, instead of being pure atmospheric air, had been the product of some previous experiment or operation, in which it had been mixed with ignited carbon. What would the veriest tyro of the laboratory say? Would he not reject the whole as unsatisfactory, and begin again, requiring the air to be brought from an unvitiated source?

Yet, this is our daily practice. We bring air to the gases which has already been employed in a separate and even destructive process, and yet expect the result to be satisfactory and the combustion complete. And when we find, instead of producing carbonic acid and water, that we have produced a large volume of *smoke*—of unconsumed combustible matter—we then set about inventing a process by which *this smoke is to be consumed*, and the evil we had ourselves produced corrected!

From what has been said, we perceive that the question of *quality* depends on keeping the supply of air intended for the use of the gas distinct from that which is intended for the use of the carbon on the bars, and allowing each to do its duty without the risk of interference from the other, either as to quantity or the abstraction of its oxygen.

SECTION VI.

OF THE INCORPORATION OF AIR AND COAL-GAS, AND THE TIME REQUIRED FOR EFFECTING THE SAME.

Having disposed of the questions regarding the *quantity* and *quality* of the air to be admitted to given quantities of coal-gas, our next consideration is, the effecting such a mixture of those relative quantities (preparatory to their chemical union) as is required by their respective natures for effective combustion.

We have seen, that the *quantity of air* admitted to a furnace, whether *plus* or *minus* what is rigidly due to *chemical union*, exercises a proportional influence on the *quantity of the combustible* which may be rendered available: we have now to consider that which will be found to exercise a still greater influence, namely, *the degree* of incorporation which can be effected between the bodies to be mixed and *the time* required for effecting it.

Now, this joint question, as to *time* and *degree*, is even more important than the previous one of *quantity*, inasmuch as the latter involves merely the amount of capability afforded to the combustible; whereas, the former involves the more comprehensive one,—whether such quantity, or, indeed, any quantity, can be made available or not: for where will be the use of allowing air to enter the furnace if it be not employed?

The positions which I propose illustrating in this section are, first, that the character and efficiency of the combustion will depend chiefly on the *degree* of incorporation we are enabled to produce between the gas and the air: secondly, that this question of *degree* depends on that of *time,—practicable, available time;* and, thirdly, that *want of time*, for this special purpose, is the great evil of the furnace.

In considering this most important branch of the subject, books furnish me with no direct information. This may be traced to the circumstance, that, in the *laboratory*, from which all our experimental illustrations come, *the want of time*, in the view here referred to, has not been felt as an injury or even inconvenience: and when we consider the comparatively small scale of laboratory operations, it will not appear remarkable, that the question of *time* has not had a more special notice. We do indeed find, in instructions to beginners, sufficiently strong and pertinent cautions to have the bodies intended for chemical union "*well incorporated*" and "*thoroughly mixed*"*;* and such like hints towards manipulatory perfection; but what this thorough incorporation means, or what it is precisely to effect, has not been sufficiently explained.

As hints of this kind do not appear to have been attended to by *practitioners on a large scale*, though considered essential by *experimentors on the small one*, it is advisable to show how that which has not demanded a more special notice in laboratory operations is, nevertheless, a most important circumstance in those of the furnace; and that the impossibility of effecting that perfect combustion on the large scale, which every chemist is able to effect on the small scale, is mainly attributable to this hitherto neglected feature,—the *want of that time* which nature requires in what may be correctly termed her own manipulations, and in working out her own purposes.

I am aware, that this is taking a new view of the *cause* of imperfect combustion; but I am urging no new principle, I am but following nature through her several stages and processes, and examining each with a view towards rendering the arrangements of our furnaces ancillary to such processes.

It seems taken for granted, in practice on the large scale, that, if air, by *any means*, be introduced to "the fuel in the furnace", it will, as a matter of course, mix with the gas, or other combustible, in a proper manner, and assume the state suitable for combustion, whatever be the nature or state of such fuel, and without any regard to time or other circumstances. In fact, that we need give ourselves no trouble about what is nature's peculiar province: and, therefore, no one inquires whether time, or preparation, or any thing be required on our part beyond the mere bringing the air and fuel together; or, rather, leaving the air to find its own way, or not, as circumstances may permit. Yet, as well might it be said, that bringing together given quantities of nitre, sulphur, and charcoal, in *masses*, was sufficient for the constitution of gunpowder. No: it is the proper distribution, mixture, and incorporation of the respective elementary atoms of those masses which impart efficiency and simultaneousness of action, and, necessarily, their explosive character:* and so, also, in the bringing mixed bodies of different kinds of gases into a state of preparation for efficient and simultaneous combustion.

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* Doctor Ure, in his *Chemical Dictionary*, puts this clearly and forcibly. Gunpowder is composed of given weights of nitre, charcoal, and sulphur, "*intimately blended* together by long pounding in wooden mortars." Again, "The variations of strength, in different samples, are generally occasioned by the more or less *intimate division and mixture* of the parts. The reason of this may be easily deduced from the consideration, that nitre does not detonate until in contact with inflammable matter: whence the whole detonation will be more speedy the *more numerous the surfaces of contact*."

In operating in the laboratory, when we mix a measured jar of an inflammable gas with a due complement of oxygen gas, the operation being performed leisurely, sufficient opportunity for their due incorporation necessarily follows, and no question as to the *want of time* arises. On the mixture being effected, it is fired, and the combustion which follows is so complete that every atom of the one gas will be found to have entered into union with its equivalent atom of the other.

In this operation the quantities are small: both bodies are gaseous: there is no counteracting or disturbing influence from the presence of other matter: the relative quantities of both gases are in saturating proportions: and, above all, the bodies to be mixed are so unaffected by current or draught that the laws which regulate the diffusion of gases have free scope to act.

But compare this correct, careful, and deliberate laboratory operation with what takes place in the furnace. First, the quantities in this latter case are large: secondly, the bodies to be consumed are partly gaseous, partly solid: thirdly, the gases evolved from the coal are never homogeneous, being part combustible and part incombustible: fourthly, these gases, as they pass over the mass of glowing matter on the bars, are forced into connexion with a large and often overwhelming quantity of the products of combustion from such glowing matter, chiefly carbonic acid: fifthly, the very air introduced is itself deteriorated in passing through the bars and incandescent fuel on them, and thus deprived of much of its oxygen: sixthly, and above all, the gases to be mixed, instead of being allowed to remain a suitable time in presence of the due proportion of air, (as in the laboratory process,) by which their diffusion would have been favoured, are hurried away by the current or draught in large masses, many cubic feet being generated in every instant of time.

All these circumstances seriously impede the process of mixing: and it may be asked, how such masses, under such counteracting influences, could possibly become incorporated; or how their several atoms or divisions, *during their flight* into the cooling region of the flues, could be enabled to select, and seize on, each its respective portions of the supporter, and duly arrange themselves for chemical union; and all, as it were, on the instant; in opposition to the counteracting force of the current carrying them into the flues and out of the influence of the required temperature of ignition, without which any *subsequent* incorporation would be useless.*

Some portions of air, it is true, do come into contact with the gas, and are ignited, but we have yet to learn how much larger is the quantity which is carried away unincorporated with air; and even how much the calorific effect of what is consumed has been deteriorated.

As this division of the subject must be new to unscientific readers, it will require more detail and illustration.

We have seen, that the *complete* combustion of a body depends on the chemical union of its atoms, or elementary divisions, with their respective equivalents of the *supporter*, oxygen;† and which necessarily implies, first, the *bringing*

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* As an instance of the effect of current in obstructing mixture, the junction of the rivers Rhone and Arve present a striking illustration on a large scale Few travellers to Geneva have omitted visiting the spot. The river Rhone, after passing through Geneva, receives the waters of the river Arve: the former being remarkably transparent, with a decidedly blue colour, whereas, those of the Arve are opaque, presenting the appearance of a mixture of chalk and water; and, notwithstanding that this latter intersects the Rhone at right angles, they run side by side for a considerable distance, presenting the curious effect of a muddy white stream on the left bank, and a clear blue stream on the right.

† We are not to suppose that oxygen is the only supporter of combustion. There are several others, as chlorine, for instance. On this head, however, the reader will find sufficient information in *Brande's Manual*, or any other work of authority.

together ; and, secondly, the mixing and duly arranging such atoms, previously to the mixture being fired for combustion.

Two questions here naturally arise. In what manner, or by what power or influence, is this intimate incorporation to be effected? and what interval of time is required for its completion?

The first question is the most difficult and complicated. It involves the whole theory of the diffusion of gases, and I may, therefore, well be justified in not entering upon it; and the more so as, for practical purposes, it is not essential. All we are called on to admit is, that, if combustion means the chemical union of the combustible and the supporter, that union must involve contiguity and arrangement of the constituents to be united, according to some fixed elementary laws; but in what form or order of collocation, or by what impulse or affection of matter, this arrangement of atoms and incorporation is effected need not now be inquired into.

The second question, however, namely, what interval of *time* is required for completing this arrangement between the elementary atoms of the bodies to be mixed, is of the very essence of the inquiry, with a view to practice, and must be logically and chemically examined.

We begin by taking for granted, that the atoms of the gaseous bodies about to be mixed are endowed with extreme mobility *inter se;* that is, the power of moving with the utmost facility and in all directions, amongst themselves; and that, by means of such power, and that peculiar agency which regulates their movements, the atoms of one class of constituents will be drawn towards those of the others with which they are respectively to form unions, either into actual contact, or within some given sphere of mutual influence, preparatory to their chemical action on each other.

To urge the necessity for this previous condition of contact or proximity would scarcely appear called for; but, as this branch of the inquiry is of the utmost importance, in a practical point of view, and that we may take nothing for granted, a short illustration may be useful.*

Let us take the familiar instance of the combustion of a number of grains of gunpowder. We place them together, *in contact*, and, on approaching a body of the due temperature for their ignition, combustion ensues; and the intervals of time occupied by the transmission of heat, from grain to grain, being inappreciable by our senses, the combustion has the appearance of being simultaneous.

But let us alter the arrangement or collocation of the several grains. Let them be placed *consecutively* in the nature of a *train*, so as to leave certain distances between them. Under this arrangement, combustion will no longer be *simultaneous*, and an appreciable interval will occur between the combustion of the several grains. Let us further suppose, that, at some part of the series, the distance between some of the grains should be greater than mutual action or influence demanded. In that case, we cannot doubt that the interruption created by such distance would stop the continuousness of the combustion, and that the grains thus separated would escape combustion.

This illustration, it is to be observed, is without reference to *chemical* action between the atoms or grains.

Let us now apply it to the case before us. Let us suppose an atom of hydrogen gas and an atom of oxygen gas brought together, as in the annexed figure, or with that kind of contact which is denominated *mechanical*, in opposition to

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* Doctor Reid, in speaking of "chemical action", lays down the following among the general rules by which it is governed:

"2252.—All chemical action consists in the more intimate union of particles of matter *previously brought into the nearest possible contact* by mixture; or in the separation of those that may have previously been attached to each other.

"2253.—No chemical action can ensue where the materials are not brought into the nearest possible contact."

chemical, and such as a drop of water and a drop of oil would exhibit when brought together: that is, by mere adhesion, without producing any change of individual character.

On heat being applied, chemical action will be induced, and chemical union instantaneously effected between them. By this union, a new body, *water*, (or rather, steam first, and then, water, by condensation,) will be formed, possessing the properties of neither hydrogen nor oxygen. Their previous states of electricity will be found to be changed: their previous joint bulk, or volume, reduced one-third: considerable heat will be evolved during the process of uniting; and this, strictly speaking, is *combustion.** Here we know, that, previous to their forming an union, the two atoms were in contact, "the closest possible contact"; meaning, within the spheres of their respective affinities and action—chemical or electrical, or whatever it may be which operates with such powerful and instantaneous force, and equal, in point of intensity and rapidity, to what we know of electricity.

But can we have a doubt, if they had *not* been so in contact, or within such range of action, that no union would have been effected? that no change of character would have been

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* When *two volumes* of pure hydrogen gas are mixed with one volume of pure oxygen gas, and the mixture inflamed in a proper apparatus by the electric spark, the gases totally disappear, and the interior of the vessel is covered with drops of pure water, *equal in weight to the* gases consumed. Again,

If pure water be exposed to the action of voltaic electricity, it is resolved into *two volumes* of hydrogen, disengaged at the negative pole, and *one volume* of oxygen, disengaged at the positive pole: so that water is thus proved, by *synthesis* and by *analysis*, to consist of two volumes of hydrogen combined with one volume of oxygen. The specific gravity of hydrogen, compared with oxygen, is 1 to 16: these numbers, therefore, represent the comparative weights of *equal volumes* of those gases; but, as water consists of *one volume of hydrogen and half a volume of oxygen*, it is obvious, that the relative *weight* of those elements will be as 1 to 8, or as follows:

Hydrogen	1 atom	1	by weight	per cent.	11·1	by vol.	1·0
Oxygen	1 do.	8	do.	do.	88·9	do.	0·5
	—	—			——		—
Water	1	9			100·0		1·0

—*Brande's Manual of Chemistry*, p. 351.

induced in either? that no heat would have been evolved? and no chemical action would have taken place? This we can no more doubt than that, in the ordinary experiment of bringing the knuckle to the ball of an electric machine to receive the charge, no electricity will pass unless the knuckle be brought *into contact*, or *within the sphere of electric influence.*

These facts must be borne in mind, this *previous* contact or contiguity of the respective and combining *atoms* of gaseous bodies being the key to the whole of the mysterious process of combustion.

But the question of *time* is now before us; and, to apply the illustration, we must extend it, from the case of *single gaseous atoms*, to that of *masses* or *bodies of gases*, each containing numberless atoms; for it is only in the mixing and incorporating of large bulks that *time* can be an object.

Let us, then, suppose diagram 3 to represent a body of hydrogen gas and a body of oxygen gas, brought together for the purpose of chemical union and combustion, in the proportions strictly required for forming steam or water; that is, the one being *equal* to the other as to the *number* of atoms, but *double* as to *bulk* or volume, as in the example already given; and this double relation of the two *masses* must necessarily be the same if that of their *atoms* be so, and *vice versa.*

Let figure 16 represent a section of this body of hydrogen, and figure 17 of the body of oxygen. Our object being to effect chemical union between these two bodies, what is to be done? To this question *practice* says, bring them together; apply the necessary degree of heat, and combustion will follow: but *chemistry* says more. Chemistry tells us, this would be only bringing the masses together: that it is not the *masses*, but their elementary *atoms* or component parts that are to combine; and, therefore, that it is these latter which are to be brought, respectively, into contact, so that *each pair of atoms* may be in a condition favourable for mutual action and union. Figure 18 represents such a state of incorporation and proximity of the combining pairs of atoms, and figure 19 the product of their combustion, namely, a volume of steam, of the bulk of the hydrogen employed, and of the exact weight of the two combining masses—not a single atom of either remaining unsaturated or uncombined. *This, then, is perfect combustion.*

If this incorporation be properly effected, that which took place with the one pair of atoms (see figure 14) will instantaneously take place *over the whole;* and this conveys a correct idea of the *kind* and *degree* of incorporation which chemistry demands.

I here again ask, can we have a doubt, that, if the atoms of each double set had *not* been thus respectively in contact, or within the range of mutual action, as illustrated by figure 18, simultaneous or entire combustion would not have taken place;* and that such atoms as might have been beyond such sphere of chemical action would have remained uncombined and unconsumed, as in the case of those grains of gunpowder which were separated, and beyond the required distance for the transmission of flame.

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* In the several figures or groupings I shall use, describing the intermediate states of incorporation before combustion, I need hardly say, that I do not affect to give the actual form or mode in which the several atoms range themselves. That we can never know ; and, indeed, it is evident that those of each *group* of atoms may be otherwise placed, and yet produce the same contiguity. All I urge is, that the atoms of each respective group which are to unite must, before firing, be either in actual contact, or within some given sphere of mutual influence, previously to their acting on each other ; and, as already observed, when we would receive the charge by bringing the knuckles to the ball of an electric machine.

Mr. Kelland observes, with respect to the mixture of particles of different kinds, "The same difference in their attractions and repulsions will produce the same effect of arranging each set *symmetrically*, so that the medium will still be one of unequal symmetry. Now, whatever be the number of particles united, such is the nature of the forces, that the system cannot remain in equilibrium ; or, at least, in stable equilibrium, except *the different sets of particles* have arrangements analogous to each other, and so distributed that there is a regular recurrence of the same form."

It will be observed, that the question of *time*, the importance of which I am now urging, has no reference to the interval employed in *the act of combustion*—that being instantaneous and simultaneous; but refers exclusively to that required for the *preparatory* mixing and incorporating; beginning at the moment when the masses are brought together, until *complete diffusion* has been effected, and the arrangement of their elementary atoms has become uniform and complete throughout, and ready for firing.

But how is this kind or degree of mixing to be brought about between bodies of such different specific gravities, seeing that a light liquid will float on the surface of a heavier one, and will not mingle unless agitated?

Fortunately, the laws which govern the motion of gaseous bodies are different from those of liquids; since the laws of gravity, which influence the latter, appear to be overborne by some other law or force, in the case of the former.

Nature, then, by her own laws, in her own way, and *in her own due time*, will, if not impeded, produce that precise state of perfect incorporation which we see is essential to combustion, but which could not have been brought about by any degree of mechanical agitation. How this is effected —under what law, or by what influence, are questions which involve the consideration of that intricate branch of chemical inquiry, designated by the term the "*diffusion of gases.*"

This subject, as already observed, was first alluded to, and these facts, (now admitted by all chemists,) first explained by that able philosopher, Dalton; and to this day the subject continues to engage the attention of the ablest men of the age.

On this inquiry, I have said, I am not going to enter, neither shall I venture to add any hypothesis of my own. I will here only refer to the admitted facts—First, that, if two bodies of *dissimilar* gases be brought together, they will, *if due time be allowed*, effect a uniform and general incorporation among their respective elementary atoms.* Secondly, that the rapidity and intensity of their chemical action and the quantity of available heat evolved will depend on the *degree* and completeness of the previous incorporation; and, thirdly, that, by such chemical action, no greater quantity of either body will enter into union or combustion than what *is rigidly due to the saturating equivalent of each.*

Let us now go a step further, and show an arrangement of the atoms of a combustible with its supporter, where they are *disproportioned* in number. Let us take carbon vapour, (the other combustible in coal-gas,) and its equivalent of oxygen (see diagram 4); namely, two atoms of oxygen to one of carbon vapour. Fig. 20 represents the body of carbon; fig. 21 that of the oxygen—double the bulk of the former; fig. 22 shows the arrangement or mixture previously to firing for combustion ; and fig. 23 the resulting product after combustion, namely, carbonic acid.

Here, as in the preceding case, on being fired not a single atom of either body remains unattached. *This, also, is perfect combustion*, the mixture or diffusion of the respective atoms among themselves having been so complete that those of each set were within the range of mutual action before being fired.

The next illustration (diagram 5) is still more important. We have hitherto taken *oxygen* alone to effect combustion with the combustible; but, as we cannot obtain that ingredient by itself, we must take it as we find it in atmospheric air. Fig. 24 represents a body of hydrogen equal to that in the first illustration (diagram 3); fig. 25, the body of air sufficient to supply its saturating equivalent of ogygen ; fig. 26, the preparatory mixture ready for firing; fig. 27, the resulting products of combustion—steam ; fig. 28 being the body of nitrogen disengaged from the air after the oxygen had been abstracted by the hydrogen.

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* Mr. Kelland observes, problem 87, "The nature of gaseous bodies is such that, if uniformity is to be expected at all, we should naturally be induced to seek it in them; and, what is more satisfactory, all gaseous bodies act similarly under similar circumstances, whether simple or compound."

It is here to be observed, that the only difference between this and the preceding example is, that *there* we used pure *oxygen*, and *here* we use *air*. This, however, brings us acquainted with the cause of the increased quantity and intensity of heat produced by the combustion of hydrogen gas in *oxygen*, above what is produced by the combustion in *air ;* although the quantities of both the combustible and the supporter have been the same in both cases. This difference arises solely from the interposition of so large a portion of useless heat-absorbing nitrogen.*

The next illustration (diagram 6) is that of the mixture and combustion of carbon vapour *in air*, and here also we find a corresponding difference, in effect, between the employment of *oxygen* and *air*. Fig. 29 represents a body of carbon vapour ; fig. 30, a body of air, supplying the requisite quantity of oxygen ; fig. 31, the preparatory mixture before combustion ; fig. 32, the resulting body of carbonic acid ; and fig. 33, the nitrogen of the air passing off uncombined. We see that this example, and that given in diagram 4, are the same in every respect *with the exception of the nitrogen.*

Having shown the separate combustion of hydrogen and carbon in *oxygen* and in *air*, our next step is to show the combustion of *both* combustibles, from their combined state as in *coal-gas;* and this brings us to what we have to deal with in the *furnace.*

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* "Le gaz *oxigène* produit, par la combustion, une chaleur beaucoup plus vive que *l'air atmospherique, parce que le gaz azote ne la partage pas* avec ses combinaisons."—*Berthollett*, vol. i., 59.

Berzelius also observes, "Celle n' est jamais plus forte que dans le gaz oxigène pur: mais plus les molécules de ce gaz sont ecartées les unes des autres par la rarefaction, *ou par le melange avec un gaz étranger*, plus aussi la chaleur qui se developpe pendant la combustion est faible. C'est pour cette raison qu'un corps qui brûle dans l'air y repand *moins* de chaleur, parce que la l'oxigène se trouve *mêlé avec une quantité de nitrogène quadraple de la sienne.*"

Let us, however, follow the same course, first showing its combustion in *oxygen*, and afterwards in *air* (diagram 7.) Fig. 34 presents us with a body of coal-gas (carburetted hydrogen); fig. 35, its equivalent of oxygen; fig. 36, their mixture preparatory to being fired; and figs. 37 and 38, the products of their combustion, namely, one volume of carbonic acid, and two volumes of steam.

This latter illustration gives us precisely the mixture effected by Mr. Gurney's admirable and scientific arrangement in what is called the "Bude light", and with which it is proposed to illuminate the Houses of Parliament, and our coast lighthouses. In this the superior intensity of the light is caused by the absence of nitrogen, and the consequent facility afforded to the atoms of the combustible gas and the oxygen for becoming more intimately incorporated before combustion.

The last illustration of the series brings us to the state of things we have to encounter in the furnace, namely, the mixture and combustion of a body of coal-gas with its equivalent of oxygen *as met with in atmospheric air* (diagram 8.)

Fig. 39 represents a body of coal-gas (the same as in the preceding example); fig 40, the required quantity of air, say ten times the bulk of the gas, to give the required quantity of oxygen; fig. 41, their mixture previous to combustion; figs. 42 and 43, the products of combustion from the three constituents of the gas; and fig. 44, the disengaged and uncombined nitrogen.

And here we cannot but be impressed with the importance of *time* for effecting the previous mixture and incorporation of the air and the gas, so as to give the necessary contact, or juxtaposition of the respective atoms of each group, on account of the enormous disproportion between the bulk of the *oxygen* employed in the previous example, and that of the *atmospheric air* employed in the present; the latter being five times greater than the former, although the quantities of *oxygen* are the same in both.

For the purpose of having these several illustrations under the eye at once, in their progressive order, and for the sake of reference, I here enumerate them, with the relative volumes of the combustible and the supporter employed in each.

No. of Diagram.	*Ingredients employed.*		*Relative volumes*	
3.	Hydrogen and oxygen,	the latter being	one-half	the volume of the former.
4.	Carbon and oxygen,		double	
5.	Hydrogen and air,		2½ times	
6.	Carbon and air,		5 times	
7.	Coal-gas and oxygen,		double	
8.	Coal-gas and air,		10 times	

Looking at the curious, symmetrically arranged groups which these diagrams present, particularly the last, in which carbon and hydrogen, oxygen and nitrogen are to be so mixed that no atom of either combustible shall be so distant from its equivalent of the supporter as to escape chemical union on being fired; remembering, also, that these four gases, when brought together for mixture, are all different, not only in specific gravity, but in their capacities for heat, we cannot resist the conclusion, that more time is required than is compatible with the present arrangement of our furnaces, for effecting that *mechanical* intermixture of their elements which will enable them electrically, or *chemically*, to combine and give out heat by producing perfect combustion; that is, the combustion of every atom of the mass. Indeed, without sufficient time, nothing short of a miracle could satisfy the required extent of diffusion. Nature, however, does not work by miracles, but by defined laws and progressive means.

The impression on men's minds, as already observed, outside the laboratory, is, that the proper degree of mixing will be brought about as naturally and expeditiously as combustion requires; and that it is only by a refinement of calculation time is supposed to be required after the bodies of gas and air are brought together.

Now, this is the great error to be combatted; and, as I set more value, under the conviction of its importance, on the necessity of having *more time* than ordinary furnaces permit, in producing that symmetry and perfect diffusion among the atomic groups, I will examine some of the evidences we have on the necessity for this required contiguity and arrangement of atoms, and the time required for producing it.

We have seen, that this mixture, *before* combustion, is *mechanical*, and preparatory to that *chemical* mixture and union which follows.—The former relating to the mere change of *position* of the atoms; the latter, to their change of *properties*.—The one, brought about under the operation of certain laws and impulses which are influenced by densities, temperatures, and other calculable forces, and necessarily *slow* in their operation: the other, by the rapid, instantaneous effect of chemical or electrical action.[*]

When, indeed, we consider the opposite states of electricity of the atoms when in contact, before their chemical union, and the change of electric relations which takes place, on their union being effected, (for the proofs of which we are indebted to Dr. Faraday and other philosophers of the present day,) and the necessity for contiguity in electrical action, it is impossible to deny the importance of this previous contiguity—not of the bodies or masses, but of their elementary atoms, from the union of which heat is produced. Now this contiguity of the *atoms* of the *different kinds* of gas is the very gist of the subject, namely, mixture, or diffusion, as the essential of chemical union and combustion.

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[*] The prevailing opinion amongst the highest authorities, both British and continental, is, that chemical action is identical with electrical agency, and induced by that disposition or tendency which bodies in opposite states of electricity have towards producing an equilibrium, as when electricity is discharged from one body or person to another.

" 'Il ne nous reste donc plus d'autre resource que de considérer le feu comme un *phenomène électrique*, qui a lieu lorsque au moment de la combinaison des corps, leurs états électriques opposés se neutralizent réciproquement, circonstance dans la quelle il reproduit du feu, de la même manière qu' il s'en manifeste dans le decharge de la bouteille de Leyde ou de la foudre."—*Berzelius*, vol. i., 212.

Combustion, Mr. Brande observes, cannot be regarded as dependant on any peculiar principle or form of matter, but must be regarded as a general result of *intense chemical action*. All bodies which act powerfully on each other are in the *separate electrical state of positive and negative*; and the evolution of heat and light may depend upon the annihilation of these opposite states, which happens when they combine.

On this head, Berzelius is explicit and satisfactory. See his "Traité des Proportions Chimiques", one passage of which I shall quote:

> "Nous croyons dont maintenant savoir avec certitude, que les corps qui sont *pres de combiner*, montrent des electricités libres opposés, qui augmentent de force, à mesure qu'elles approchent plus de la temperature à la quelle la combinaison a lieu, jusqu' à ce que, *à l'instant de l'union*, les électricités disparaissent avec une elévation de température souvent si grande qu' il eclate du feu. Nous avons, d'autre part, la même certitude, que des combinès, exposés sous la forme convenable, à l'action du courant électrique, sont separés, et recouvrent leurs premières propriétes chimiques et électriques, en méme temps que les electricités qui agissent sur eux, disparaissent.
>
> "Dans l'état actuel de nos connaissances l'explication la plus probable de le combustion et de l'ignition qui en est l'effet, est donc, que dans toute combinaison chimique, il y a neutralization des électricités opposés, et que cette neutralization produit le feu."—Page 46.

But it is the *rate* at which the process of diffusion proceeds which affects the question of *time*. On this head we have ample evidence, that gases, although they will mingle by their atoms *effectually* and *throughout*, do not mingle so *rapidly* as is generally supposed; and that their rates of diffusion may even be the subject of calculation. Mr. Kelland, who has elaborately calculated many of their movements, observes, that, "from the experiments and admirable views of Dr. Dalton, we may conclude, that, when different gases are brought together, they will intermingle with each other *gradually*, offering no other resistance (in the words of Dalton) to the mixture, than the opposition which pebbles present to the motion of water."*

Thus we find, that, even with the aid which small quantities, correct proportions, and deliberate mixture afford, the operation is still a *gradual* one, and dependant on the extent of its contact of atoms with those of the air. How, then, must the mixture be retarded when the quantities are large; irregular in proportions; in a rapid onward motion as in a furnace; and the contact of atoms necessarily obstructed? Dr. Reid, in his "Elements of Chemistry," when describing the detonating mixture, directs "that the oxygen be *well mingled* with the hydrogen." Here, deliberate measures are taken for the diffusion of a mere phialful, yet we take no pains to have these same ingredients "*well mingled*" in the furnace!

In the "Experimental Researches on the Diffusion of Gases," by Mr. Graham, we have abundant proof of the absolute necessity for giving time. In one case he observes, "the receiver was filled with 75 volumes of hydrogen and 75 of olefiant gas, agitated and allowed to stand over water for *twenty-four hours, that the mixture might be as perfect as possible.*" In general, he allowed four hours to elapse before he considered the gases adequately mixed.

Professor Daniell finds, that, even in laboratory experiments, it is essential to give an excess of oxygen to secure an adequate portion reaching each atom of the gas to be consumed, no more, however, being consumed than its due equivalent of oxygen.†

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* "On the Theory of Heat," by Philip Kelland, M. A., Fellow of Queen's College, Cambridge.

† "In the process which has been described for collecting the products of the detonation of hydrogen and oxygen, it is necessary *that they be mixed very accurately*, in the proportion of two of hydrogen to one of oxygen. In these proportions they enter into combination, and in none other, and if either were in excess, the surplus would be left after detonation."—*Daniell's Introduction to Chemical Philosophy.*

But the observations of Professor Faraday should satisfy us at once on the question of *time*, and justifies my attributing so much importance to this hitherto neglected feature in the process of combustion on the large scale. In his "Chemical Manipulations," p. 360, Dr. Faraday says, "It will be proper to observe, that, although in making mixtures of gases, they will become uniform without agitation, *if sufficient time be allowed*, the period required will be *very long*, extending even to hours, in narrow vessels. If hydrogen be thrown up into a *wide* jar full of oxygen, so as to fill it, and no further agitation given, the mixture, *after the lapse of several minutes*, will still be of different composition above and below." Here are *several minutes* proved to be necessary in effecting adequate mixture in a jar full of the gases, whereas we cannot afford even *several seconds* for the mixing of a furnace full.

Here is proof sufficiently strong in favour of the point of *time* which I am contending for; yet, in managing combustion on the large scale, this condition, as to time, is wholly overlooked, although the question of economy eminently depends on that of perfect diffusion.

The effect of varying densities, or specific gravities, in gases, is also remarkable on the point of time. Mr. Kelland observes, that the rapidity of mixing is dependant on the relative densities of the gases.* Dr. Dalton found "the mobility of gases to be inversely as their densities." Dr. Reid proves, that gases of different densities *do not mingle rapidly*.†

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* "The rapidity of mixing is *dependant* on the relative densities of the gases, and appears, from Mr. Graham's experiments, to be such that the mass which a gas A, in any small time, communicates to the gas B, is to the mass B which it receives, as the square root of the density of A to the square root of the density of B."—*Problem* 89.

† "Fill a jar half full of oxygen, and then cautiously fill it up with carbonic acid. Then remove the cork and introduce a suspended candle. It burns brilliantly in the upper stratum of oxygen, but is extinguished in the carbonic acid below, being kindled again, as it is again drawn upwards into the oxygen. Hence gases of dif-

The experiments of Professor Graham also prove how influential is the difference of density in aiding or retarding diffusion, and he even comes to the conclusion, that "the specific gravity of gases can be determined by experiment, on the principle of diffusion, with greater accuracy than by ordinary means." *

I find, also, a satisfactory illustration given by Berzelius, vol. i., pages 234 and 235, of the necessity for giving *time* for the due mixing of the constituents of a combustible gas with its supporter previously to combustion, but it is too long for introduction here.

I might here add many illustrations from Dr. Faraday, of the causes of the acceleration and retardation of the processes of mixing and combining, but it would draw me too much from the practical application of the facts before us. I must, therefore, content myself with referring to his able "Experimental Researches in Electricity," a work which will amply repay the scientific inquirer.

The work of Mr. Daniell, Professor of Chemistry, King's College, London, in which he has presented to students in chemistry an elementary view of the discoveries of Dr. Faraday in electrical science, is also a work well worthy perusal by those who desire to go deeper into the consideration of what belongs to chemical action, and its connexion

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ferent densities do *not mingle rapidly* with each other, at least, to any great extent. But, if the oxygen and carbonic acid be left together *for a considerable time*, they gradually diffuse themselves through each other, part of the heavy carbonic acid rising, while a portion of the lighter oxygen descends."—*Elements of Chemistry, by Dr. D. B. Reid*, p. 692.

* A paper, by Professor Graham, containing the results of a most able inquiry into the Laws of the Diffusion of Gases, was read before the Royal Society, of Edinburgh. In that paper, the object of the Professor is to establish the following law, namely, that "the diffusion, or spontaneous intermixture, of two gases in contact, is effected by an *interchange in position* of indefinitely minute volumes of the gases, which volumes are not necessarily of equal magnitude, being, in the case of each gas, inversely proportional to the square root of the density of that gas."

with electricity, in the process of combustion, and is strongly illustrative of the principle I am here enforcing.

In Dalton's paper, read to the Manchester Philosophical Society, Jan. 28, 1803, "On the Tendency of Elastic Fluids to Diffusion through each other," he arrives at this conclusion, "that a lighter elastic fluid cannot rest upon a heavy one, as in the case of liquids; but that they are constantly active in diffusing themselves through each other *till an equilibrium is effected*, and that *without any regard to their specific gravity*, *except so far as it accelerates or retards the effect*." This is precisely the case before us, and to the point, on this branch of the subject; the several gases meeting at the bridge of a furnace being so various as to their relative specific gravities, as shown in the following scale—air being taken as unity:

	Specific Gravities.	*Weight of* 100 *cubic inches in grs.*
Hydrogen	0·0689	2·137
Carbon vapour	0·4210	12·955
Carburetted hydrogen	0·5590	17·360
Carbonic oxide	0·9730	30·186
Nitrogen	0·9785	30·346
Bi-carburetted hydrogen	0·9820	30·440
Atmospheric air	1·0000	31·011
Oxygen	1·2060	34·346
Carbonic acid	1·5240	47·283

Here we have many different kinds of gaseous bodies, all of which encounter each other in the furnace, struggling

The following exhibits the results of his numerous and accurate experiments, illustrative of the above.

TABLE

OF EQUIVALENT DIFFUSION-VOLUMES OF GASES: AIR=1.

	By experiment.	*By theory.*	*Specific gravity.*
Hydrogen	**3·83**	**3·7947**	**0·694**
Carburetted hydrogen	**1·344**	**1·3414**	**0·555**
Olefiant gas	**1·0191**	**1·0140**	**0·972**
Carbonic oxide	**1·0149**	**1·0140**	**0·972**
Nitrogen	**1·0143**	**1·0140**	**0·972**
Oxygen	**0·9487**	**0·9487**	**0·111**
Sulphuretted hydrogen	**0·95**	**0·9204**	**0·180**
Protoxide of nitrogen	**0·82**	**0·8091**	**1·527**
Carbonic acid	**0·812**	**0·8091**	**1·527**
Sulphurous acid	**0·68**	**0·6708**	**2·2223**

together and exercising their respective attractive forces for the oxygen; yet all tending towards the formation of an uniform mass and equilibrium, *if time be allowed*. These bodies, we see, vary in their specific gravities, from hydrogen, the lightest of all known gases, up to carbonic acid, one of the heaviest; thus presenting the greatest natural impediment to the formation of that equilibrium which is essential to rapid and perfect combustion.

In the above table we see, that air is nearly double the density of the carburetted hydrogen (coal-gas) with which it is to mingle; 100 cubic inches of the latter weighing but 17 grains, while 100 cubic inches of air weigh 31 grains. And the difference is still greater between air and hydrogen, (of which latter four-fifths of coal-gas is constituted,) 100 cubic inches weighing but 2·137 (2 1-10th grains); the air, consequently, being nearly fifteen times heavier than that gas: and these are the very bodies we expect shall mingle, and coalesce, and form an equilibrium, *on the instant*, in the furnace.

Now this brings us to the conclusion, that, as we cannot *force* the gases (coal-gas and oxygen, for instance) to mingle with sufficient rapidity, under the ordinary circumstances of the furnace, our views should be directed to the effecting such modifications of that furnace as will aid nature in those arrangements which are essential to combustion, rather than in obstructing them, or resting satisfied with what erroneous custom has established under the attractive, but fallacious, name of "*practice*." Here, as chemistry points out the evil we have to contend with, so chemistry should guide us in applying the remedy.

I conclude this important division of the subject by the following short recapitulation:

1st. Combustion, by which we obtain heat, is *chemical union* induced between the combustible and the supporter.

2d. To effect this union, the bodies about to be united must first be *brought together*, either into actual contact, or within their respective spheres of chemical action.

3d. As the chemical unions to be effected are not between the *masses*, but the *elementary atoms* of which they are respectively composed, so the *previous* mixture and contiguity must have reference to such *atoms*, and not to the *masses*, or aggregate of atoms.

4th. Complete, perfect *mixing* means effecting such a degree of incorporation that, if portions be taken from different parts of the mass, they will always present groups of the exact same constituents, or composition : the whole being thus homogeneous and symmetrical throughout ; each atom of the combustible being contiguous to its equivalent atom, or atoms, of the supporter.

5th. To effect this degree of incorporation *time* is required, according to the special nature of each of the bodies to be mixed ; inasmuch as these bodies, when brought together, are of such varying densities and temperatures.

6th. The operation of mixing will be retarded, or accelerated, and a longer time required, according to the nature and number of the bodies to be mixed ; those mixtures in which the combustible and the supporter can be brought into *closer contiguity* (as hydrogen and oxygen) being effected in a shorter time, and with more energy and intensity, than where they are at greater distances from each other, by the interposition of other gases, as in the case of hydrogen and air.

7th. Finally, the quantity of available heat obtained will be in the ratio of the number and simultaneousness of the unions which will take place, and the contiguity of the uniting atoms *at the time of being fired.*

The importance and necessity of *time* being established, the next consideration will be, how to meet the case of that

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want of time which is occasioned by the circumstances under which combustion takes place in a furnace as ordinarily constructed.

I avail myself of this opportunity of stating the opinion of one whose authority will not be questioned, in confirmation of the views taken by me on this part of the subject. Being desirous of having my doubts cleared up on some points, I consulted Mr. Daniell professionally, and here annex his reply. Professor Daniell, it will be observed, goes even farther than I have as to the *quantity* of atmospheric air to be supplied in effecting the preparatory mixture of the combustible and the supporter: urging the necessity, even in careful laboratory practice, of providing *an excess* of the supporter, as a means of ensuring full and saturating diffusion, and preventing the possibility of any of the combustible passing away uncombined and unconsumed.

OPINION.

"King's College, 8th August, 1840.

"There can be no doubt, that the affinity of hydrogen for oxygen under most circumstances is stronger than that of carbon. If a mixture of two parts of hydrogen and one of carbonic *acid* be passed through a red-hot tube, water is formed, a portion of charcoal is thrown down, and carbonic *oxide* passes over with the excess of hydrogen.

"With regard to the different forms of hydro-carbon, it is well known, that the whole of the carbon is never combined with oxygen in the processes of detonation or silent combustion, *unless a large excess of oxygen be present*.

"For the complete combustion of olefiant gas, it is necessary to mix the gas with *five* times its volume of oxygen, *though three only are consumed*. If less be used, part of the carbon *escapes combination*, and is deposited as a black powder. Even sub-carburetted hydrogen it is necessary to mix with more than twice its bulk of oxygen, or the same precipitation will occur.

"It is clear, therefore, that the whole of the hydrogen of any of these compounds of carbon may be combined with oxygen, while a part of their carbon may escape combustion, and *that* even when enough of oxygen is present for its saturation.

"That which takes place when the mixture is designedly made in the most perfect manner must, undoubtedly, arise in the common processes of combustion, where the mixture is fortuitous and much less intimate. Any method of ensuring the complete combustion of fuel, consisting partly of the volatile hydro-carbons, *must be founded upon the principle of producing an intimate mixture with them of atmospheric air, in excess*, in that part of the furnace to which they naturally rise. In the common construction of furnaces this is scarcely possible, as *the oxygen of the air, which passes through the fire bars*, is mostly *expended upon the solid part of the ignited fuel with which it first comes in contact.*

"J. F. DANIELL.

"To C. W. Williams, Esq., &c. &c."

SECTION VI.

OF THE MODE OF EFFECTING THE INCORPORATION OF THE COAL-GAS AND AIR, IN THE FURNACE, PREPARATORY TO COMBUSTION.

PROFESSOR DANIELL, in the opinion just quoted, states the true principle on which any improvement in our furnaces for ensuring the complete combustion of bituminous coal must be founded, namely, the producing an intimate previous mixture between the gaseous portion and atmospheric air.

Keeping this principle in view, I here propose considering the mode of introducing air to the coal-gas, so as most effectually to aid this process of diffusion. This division of the subject involves the practical application of the principles here developed, and is, in fact, a consideration of the best mode of modifying the arrangements of the furnace and flues that they shall best harmonize with the chemical conditions under which combustion takes place.

On this head we find so many convincing illustrations of what nature requires, and what a judicious mode of bringing air to the gas can effect, in a common candle and in the

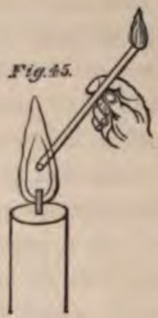
Argand lamp, that I shall, in the first instance, examine these two exemplifications of gaseous combinations and combustion, in the manner adopted by the best British and continental chemists, and then apply their illustrations to the mode which I propose suggesting. I here, therefore, give a summary of what has been said on this subject; and, as the practical remedy which I shall conclude by suggesting is drawn from the irresistible inferences arising out of the statements of so many competent professors, I shall be the more particular in their examination.

Mr. Brande observes, "In a common candle, the tallow is drawn into the burning wick by capillary attraction, and there converted into vapour, which ascends in the form of a conical column, and has its temperature sufficiently elevated to cause it to combine with the oxygen of the surrounding atmosphere with a temperature (the result of the combination) equivalent to a *white heat.* But this combustion is *superficial only*, the flame being a thin film of white hot vapour, enclosing an interior portion, *which cannot burn for want of oxygen.* It is in consequence of this structure of the flame that we so materially *increase its heat*, by propelling a current of air through it by the *blow-pipe;* or supplying its interior with oxygen, as in the gas-jet suggested by Mr. Daniell (Phil. Mag., 3d series, 2, 57.) The perfection of the Argand lamp is also referable to the same cause."

Doctor Reid observes, "The flame of a candle is produced by the gas formed around the wick acting upon the oxygen of the air: *the flame is solely at the exterior* portion of the ascending gas. All *without* is merely heated air or the products of combustion; all *within* is *unconsumed gas rising in its turn* to affect (mingle with) the oxygen of the air.

"If a glass tube be introduced within the flame of a lamp or candle, (as represented in fig. 45,) part of the unconsumed gas passes through it, and may be kindled as it escapes." (Mr. Brande has given the same illustration in his "Manual of Chemistry.")

Fig. 45.



Berthier, vol. i., p. 177, observes, "The flame assumes the form of a sharp cone, with a hemispherical shape at the lower part. It presents four distinct parts: namely, first, the *base*, of a sombre blue: this is the gas which burns with difficulty, because it has not yet acquired a sufficiently high temperature; secondly, an *interior dark cone:* this is combustible gas *highly heated, but which does not burn, because it is not mixed with air;* thirdly, the *brilliant conical envelope:* in this part, combustion takes place with a deposit of carbon; fourthly, a *conical envelope*, which gives but little light, *('tres peu lumineuse,')* surrounding the whole flame, extremely thin or attenuated, *('extremement mince,')* and which is thickest at the top. Combustion is complete in this part, and it is at its contact with the *luminous* envelope that the temperature is the highest."

Berzelius, vol. viii., p. 151, observes, of the flame of a candle,—At its base we perceive a small part of a deep blue colour. In the middle is a dark part which contains the gas evolved from the wick, but which, *not being yet in contact with the air, cannot burn:* outside of this is the brilliant part of the flame. We also perceive, on the confines of this latter, a thin, faintly luminous envelope, which becomes larger towards the summit of the flame. It is there that the flame is hottest.* Dr. Thomson, in his work on "Heat and Electricity," and Dumas, in his "Traité de Chimie appliquée aux Arts," give similar illustrations of the combustion of the gas in the flame of a candle. Dr. Ure observes, "Nothing places in a clearer light the heedlessness of mankind to the most instructive lessons than their neglecting to perceive the difficulty of duly intermingling air with inflammable vapours, for the purpose of their combustion, as exhibited in the everyday occurrence of the flame of a tallow candle, or common oil lamp; for, though this flame be in contact, externally, with a current of air created by itself, yet a large portion of the tallow and oil passes off unconsumed, with a great loss of the light and heat which they are capable of producing."

All these authorities, we see, agree in the main facts: *first*, that the dark space in the centre of the flame is a body of unconsumed gas *ready for combustion*, and only waiting the *preparatory* step—the *mixing*—the *getting into contact* with the oxygen of the air: *secondly*, that that portion of the gas in which the due mixing has been effected, and which, therefore, becomes inflamed, forms but a thin film on the *outside* of such a body of unconsumed gas: *thirdly*, that the products of the combustion of the gas form the transparent envelope, which may be perceived on close inspection: *fourthly*, that the collection of gas in the *interior* of the flame cannot burn *there* for want of oxygen.

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* "Si l'on considère la flamme d'une chandelle, on voit qu'elle se compose de plusieurs parties dont on peut aisément distinguer quatre. A sa base, on apperçoit une petite partie d'une bleu foncé, qui va toujours en diminuant à mesure qu'elle s'eloigne de la meche, et qui disparoit tout-à-fait là où les côtés de la flamme s'elevent verticalement. Au mileau de la flamme, est une partie obscure qu'on apperçoit au travers de la partie brilliante. Cette partie renforme les gaz émanés de la mèche qui, *n'etant point encore en contact avec l'air, ne peuvent pas brûler.* Autour d'elle est la partie brilliante de la flamme. En outre, lorsqu'on regarde avec quelqu' attention, on voit sur les confins celle-ci de une mince enveloppe peu lumineuse qui devient plus large vers le sommet de la flamme. C'est là que la combustion des gaz s'opere, et *que la flamme est la plus chaude.*"

Dr. Reid uses a remarkable expression, which involves the whole question of *current*, *time*, and *place*. "The flame is solely at the exterior portion of the ascending gas; all without being merely heated air, or the products of combustion; all within, unconsumed gas, *rising in its turn* to affect the oxygen of the air."

Here let the questions be answered:—Why does the *outside* portion alone—this mere surface of the interior body of gas, enter into combustion? and why does the *remainder* continue unconsumed? Berzelius answers, "The gas cannot be burned *there*, because the air which is *able to penetrate so far* has already lost the greatest part of its oxygen."*

Mr. Brande puts this with equal force. "This combustion," this chemical union between the gas and the oxygen of the air, "is but *superficial* only, the flame being a thin film of white hot vapour, enclosing an interior portion *which cannot burn for want of oxygen.*" Why? What prevents it? Why is this flame *superficial* only? Why is there a want of *oxygen*, seeing there is no want of *air?*

Now, these questions involve the whole of the case of the *furnace:*—they reveal the difference between perfect and imperfect combustion. The bodies of gas and air have, it is true, *free access* to each other: the gas is intensely hot:—yet, *time is wanting* for their due mixture. Thus, diffusion and combustion only proceed, *pari passu*, as the constituent atoms of the gas, "*taking their turn*," are enabled to get into contact with their respective equivalent atoms of atmospheric oxygen.

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* "Quant à l' espace conique interne, il est remplis de gaz combustible qui ne peuvent pas y bruler completement, parceque l'air qui parvient à penetrer *jusque-là* a deja perdu la plus partie de son gaz oxigène."

If adequate mixture and diffusion could be effected without this demand *on time*, (and which opinion, we must conclude, is the general one, seeing that nothing has been attempted to show that more time was considered necessary,) how does it happen, that so small a bulk of gas as is contained in this "dark central cone" of the flame of a candle should have any difficulty of obtaining its supply of oxygen, in the midst of an unrestricted supply of air? And, if this small portion of gas (although at a heat, in the centre of a flame, equal in intensity to "a *white heat*") has such difficulty in obtaining *adequate contact* with its equivalent of oxygen, how can we expect so enormous a mass of gas as is generated in the furnace should be adequately supplied, under the hurried circumstances occasioned by the draught?*

How much more applicable, then, would be the words of these experienced chemists to *such* a mass: that "it cannot burn for want of oxygen."—(Brande.) That, "not being in contact with air, it cannot burn."—(Berzelius.) That it has "to wait its turn" to mingle with the air.—(Reid.) That it does not burn, "parce qu'elle n'est pas melangè d'air."—(Berthier.) That, being beyond the necessary contact, "hors de ce contact," it cannot burn *in the same time*.—(Dumas.)

I have not hitherto quoted Sir Humphry Davy on this head, for his whole "Researches on Flame" go in corroboration of the facts here stated, and the inferences drawn by so many competent authorities.*

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* "By experiments with Dr. Wollaston's Differential Barometer, made in several factories, where both high and low pressure steam was employed, I found, that the aërial products of combustion from the boiler furnaces flew off with a velocity of fully thirty-six feet per second, a rate so rapid as to preclude the possibility of the hydrogenated gases from the ignited coals becoming so duly blended with the atmospheric oxygen as to be burned. It is well known, that elastic fluids, of different densities, such as air and carburetted hydrogen, intermingle *very slowly*; but, when the air becomes considerably carbonated, as it does in passing through the grate, and, consequently, heavier, it will not incorporate at all with the lighter combustible gases above it, in the short interval of the aërial transit through the furnace and flues. Thus, there can be no more combustion amidst these gases and vapours than in the axis of a tallow candle flame."—*Dr. Ure's Letter to the Author*.

If, then, the free, unrestricted access of air on all sides of this small flame is not able, by force, attraction, or the laws of diffusion, to form a due atomic mixture, in time for ignition, *a fortiori*, it cannot do so when the supply of air is *restricted* and that of the gas *increased*.

The Argand lamp furnishes a strong corroboration of these principles. This lamp (whether with oil or gas) differs from the ordinary one merely in this, that air is introduced into the centre of the flame; thus giving it access at the *inside* as well as the *outside* of the circular body of gas to be consumed. Now, the advantage of this alteration consists merely in its enlarging the accessible *surfaces for contact* of the atoms to be mixed; and which, being thus *nearly doubled*, gives to double the number of atoms the means of effecting a juxtaposition, or contact, *in the same space of time*: for, after all, by the *criteria* of *time* and *contact of atoms* must any improved plan be tested; since, in Professor Daniell's words, its efficiency must be "founded on the principle of producing an *intimate mixture*."

Dr. Reid, speaking of the Argand lamp, (see fig. 46,) observes, that the intensity of the heat is augmented by causing the air to enter in the middle of a circular wick, or *series of gas-jets*, so that more gas is consumed *within a given space* than in the ordinary manner.

But why is more gas consumed *within this given space?* Solely because more capability for mixture is afforded, and a greater number of accessible points of *contact* obtained, arising out of this series of jets. This may be seen in fig. 47, where the inner surfaces, *a a*, are shown in addition to the outer ones, *b b*.

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* "In looking steadfastly at flame," he observes, "the part where the combustible is volatilized is seen, and it appears darker, contrasted with the part in which it *begins* to burn, that is, where it is *so mixed with air* as to become explosive."

Fig 46

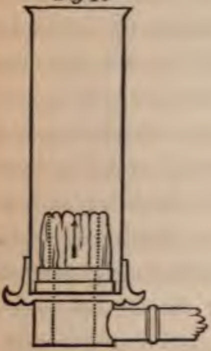


Fig 47

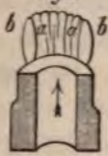
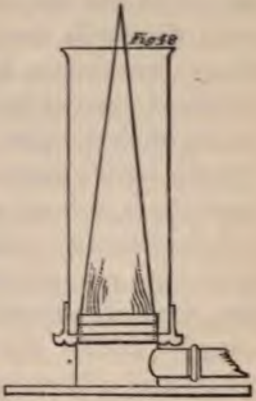


Fig 48



"If the aperture," he observes, "by which air is admitted into the interior of the flame, be closed, the flame, represented in fig. 46, immediately assumes the form shown in fig. 48; part of the supply of air being thus cut off, it extends farther into the air before it meets with the oxygen necessary for its combustion": the *length*, upwards, of the flame being always in proportion to the heat below—to the quantity of gas generated—and to the strength of the ascending current.

In this case, the flame, instead of being short, white, cylindrical, and brilliant—without smoke, and giving out much heat and light—becomes instantaneously of a murky red colour, of a long conical shape, with much smoke, and diminished heating and lighting properties.

Here we trace the *length* of the flame to the slow progressive rate, consecutive character, and diminished rate of mixing and combustion, occasioned by the want of an adequate number of obtainable points for mutual access, within any given time, between the separate constituents of the gas and the atoms of oxygen from the air. In this case, (by stopping the admission of air to the centre of the flame,) the body of gas evolved from the *inward* side of the circular wick becomes chemically decomposed: that is, resolved into its separate constituents, hydrogen and carbon, by the heat of the film of white hot flame which encircles it; but, not meeting the required supply of oxygen, (which has now to come from the *outside* current of air,) these constituents ascend uncombined, and, not meeting the supply *until too late*—until the ascending current has carried them beyond the temperature required for chemical action, both necessarily pass away unconsumed; the carbonaceous constituent losing its gaseous character, assuming its former colour and state of a black pulverulent body, and becoming true smoke.

The enlargement or elongation of the flame, therefore, so far from being an indication of increased combustion, is direct evidence of the contrary; and it will hereafter be shown, that the *length* of visible flame bears no relation to the extent, much less to the intensity, of combustion or the quantity of evolved heat: flame being, in fact, not combustion, but merely an intermediate stage in that process, as far as the carbon is concerned.

The examination of these successive processes and effects, in the flames of the candle and lamp, has always been considered so instructive by chemists, and offering such means of observing nature in her efforts to effect her purpose, that great attention has ever been paid to it. A similar study by our practical mechanics and "smoke-burning" inventors would enable them to perceive the great chemical errors on which their patents are founded.

The conclusions we draw from this analytical examination of the flames of the lamp and candle, and which we have now to apply to the furnace, are, that the gas evolved from the combustible, be it oil or coal, "cannot burn" until its constituent atoms have come into contact with their equivalent atoms of oxygen from the air; that the want of heat was not the primary, but the induced or secondary cause of this want of burning faculty; and that the ascending current had destroyed the chance of subsequent ignition by carrying the gas into the cooling region of the air, by which the necessary diffusion came too late for ignition. Thus, in the case of the lamp, as well as the furnace, the necessary *time* is unattainable, and, therefore, diffusion is equally so, except by the compensating alternative of increased *surface* and its affording an increased number of points for mutual contact in any given time.

Many illustrations might here be given as to the value of the compensating power of increased *surface* in lieu of *time*. Among these may be mentioned, that produced by numerous jets of water in reducing the temperature of the surrounding air. The well-known cooling effect of a shower of rain is caused by the increased surface of the aqueous particles presenting increased facilities for the absorption of heat.

I have dwelt particularly on this part of the subject, as so many errors in the admission of the air to the furnace are clearly referable to the neglect of this first principle of chemical union,—the bringing the combustible and the supporter into contact, not by their *masses*, but by their constituent and elementary *atoms;* and which, though so well understood and practised in the laboratory, has not been sufficiently distinguished and dwelt on by chemical writers as to enforce attention upon practical men.

In looking for a remedy for the evils arising out of the hurried state of things which the interior of a furnace naturally presents; and observing the means by which the gas is effectually consumed in the Argand lamp, it seemed manifest, that, if the gas in the furnace could be presented, by means of *jets*, to an adequate quantity of air, as it is in the lamp, the result would be the same: namely, a quicker and more intimate mixture and diffusion, and, consequently, a more extensive and perfect combustion. The difficulty of effecting a similar distribution of the gas in the furnace, by means of jets, however, seemed insurmountable: one alternative alone remained, namely, that, since the gas could not be introduced by jets into the body of air, *the air might be introduced by jets into the body of gas.*

This, then, is my remedy. This is the means which I adopt, and by which I effect a complete combustion of the gases in the furnace, as we do in the lamp. Professor Brande has so clearly described the operation of the jet that I avail myself of his remarks in elucidation of the result produced by a jet of air into a body of gas, and the analogy it bears to that of a jet of gas into a body of air.*

This process meets the entire difficulties of the case as to time, current, temperature, and quantity. By this means, the process of diffusion is hastened without the injurious effect of cooling; and which always takes place when air is introduced by large orifices.

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* "When air is admitted in front of the furnace, or through or over the fuel, it obviously never can effect those useful purposes which are, at once, obtained by admitting it in due proportion to the intensely-heated inflammable vapours and gases, or, in other words, to the products of the distillation of coal, at such temperature that they may take fire in its contact. In this way, each jet of air which you admit becomes, as it were, the source or centre of a separate flame, and the effect is exactly that of so many jets of inflammable or coal gas ignited in the air; only, in your furnace, you invert this ordinary state of things, and use a jet of air thrown into an atmosphere of inflammable gas, thus making an experiment upon a large and practical, which I have often made on a small and theoretical scale, in illustration of the inaccuracy of the common terms of '*combustible*' and '*supporter of combustion*,' as ordinarily applied.

"I fill a bladder with coal-gas, and attach to it a jet, by which I burn a flame of that gas in an atmosphere of, or a bell glass filled with, oxygen: of course, the gas burns brilliantly, and we call the gas the combustible, and the oxygen the supporter of combustion. If I now invert this common order of things, and fill the bladder with oxygen and the bell glass with coal-gas, I find, that the jet of *oxygen*

In this view of the case I was strengthened, by observing the effect of a jet of air thrown by means of a blow-pipe into the body of gas—the "dark central cone" of the flame of a candle, and where, if properly managed, the due equivalent of air may be brought into contact with the gas without any injurious cooling effect.

The difference, then, between the application of air by means of *the jet*, and that of the ordinary action of the atmosphere, consists solely in the increased surface it presents for mutual contact in any given unit of time, and by which a large quantity is so introduced as to meet its corresponding equivalent quantity of gas, while the latter retains the requisite temperature.

And let us here examine how far this mode of introducing air to the combustible gases in the furnace is analogous (as to its power of aiding diffusion) to that produced by a blow-pipe. Let fig. 49 represent a section of one of these diffusion jets; *a a* will represent the *exterior* surface of the jet or column of air, impinging, by reason of its onward motion, against the *interior* surface, *g g*, of the body of gas to be consumed; and through which it forces for itself

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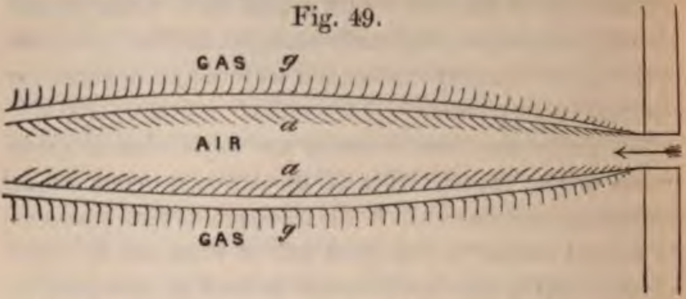
may be inflamed in the atmosphere of *coal-gas* with exactly the same general phenomena as when the jet of *coal-gas* is inflamed in the atmosphere of *oxygen*. This is precisely your process. You admit a number of jets of air into a heated, inflammable atmosphere, and so attain its combustion in such a way as to produce a great increase of heat, and, as a necessary consequence, destroy the smoke. You, in fact, convert what is commonly called smoke into fuel, at the *time when* and *place where* this combustion can be most effectively brought about."—*Professor Brande's Letter to the Author.*

On the subject of the *jet* Dr. Ure also observes:—"In the case of great steam-boiler furnaces, since these are fed at short intervals, your plan of distributing atmospheric air, in a regulated quantity, by numerous jets, through the body of the gasiform matter, is peculiarly happy, and must extract the whole heat which the combustible is capable of affording; and your mode of supplying atmospheric oxygen will prevent the possibility of the carbon of the coals escaping in the state of *carbonic oxide* gas, whereby, at present, much heat is lost in our our great furnaces."—*Dr. Ure's Letter to the Author.*

a passage, forming the column, or hollow double cone, shown in the figure.

Fig. 49.



Here the appearance as well as the operation corresponds with that of the blow-pipe, conveying the idea of a jet of actual *flame*, rather than of *air*, so instantaneous is the combustion when equivalent atoms approach each other, and so efficient is the operation, by means of their extended surfaces, in aiding atomic diffusion. Here (as also in the blow-pipe) the process differs from that of the flame of a candle, in being *reversed;* the air being *interior* in the former, and *exterior* in the latter, as explained by Berzelius.*

Thus we see, that the peculiarity as to the action and value of the *jet* arises from the circumstance of its forcing or creating, as it were, *for itself*, a larger surface for contact, by which a greater number of elementary atoms of the combustible and the supporter, the "*comburant*", gain access to each other in any given time. The "solar lamp" (a great improvement of the Argand lamp) is an illustration of the effect of increased surface created by virtue of an impinging current on the *outside*, as the blow-pipe does on the *inside*, of the mass to be consumed.

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* "Si donc, avec le bec d'un chalumeau, on dirige un courant d'air dans le milieu de la flamme, on voit apparaître devant l'ouverture de l'instrument une flamme bleue, longue et étroite, et qui a seulement changé de forme, se trouvant alors concentrée *au milieu* de la flamme, et constituant un cylindre etroit, au lieu *d'environner* la flamme."—Vol. viii., 152.

The space between the two surfaces of air and gas, *a* and *g*, in fig. 4, represents the "thin film of white hot vapour", or flame, (see page 101,) where combustion is carried on with the greatest energy. The increased calorific power produced by this mode of acting, *by jet*, will, therefore, be in the ratio of the entire exterior surface of this visible cone of flame to the sectional area of the orifice alone.

But the value of the jet (as a diffusive power) arises from this, that it creates not merely an enlarged surface of air, but a corresponding enlarged surface of gas, both having, at the same time, "the nearest possible contact" over the whole of these artificially produced surfaces.

This diffusion, so produced by mere pressure of the atmosphere, has a striking advantage (for the purposes of the furnace) over that created by force and injection through the blow-pipe, namely, that by the former no more air will enter by any one orifice than is required, and can be absorbed, beneficially, by the gas with which it there comes in contact; nature, as it were, not overcharging herself: whereas, in the case of the latter, (the blow-pipe,) much judgment and management are required as to the quantity of air injected to prevent overcharging. For, if (by the blow-pipe) this quantity be *minus* of what the surface portions of the gas require for saturation, that portion which does not receive its equivalent will pass away without aiding in the operation.[*]

On the other hand, if the quantity be *plus* of the saturating equivalent of the gas, a cooling effect will be produced, even though the air injected be at a high temperature. For, let the temperature of the admitted air be what it may, it must

[*] "Pour produire la plus forte temperature possible, on doit souffler avec un certain degré de force ménagé: si l'on donne trop de'air, la portion qui ne se consume pas *refroidit la flamme*; si le souffle est trop faible, la combustion n'est pas assez vive, et la chaleur n'atteint pas son *maximum*."—*Berthier*, vol. i., p. 178.

be considerably below that of the envelope of flame, and, therefore, will produce a commensurate cooling effect.†

The evil to be remedied, then, in the furnace, is not the want of a sufficiently elevated temperature; neither can the introduction of heated or hot air remove it. The evil, even where the proper gross volume of air is admitted, arises from the approach or contact of any portions of such gross volume of air, to portions of gas, (however small they may be,) beyond what can instantaneously combine with such separate the portions of gas; that is, being in excess of what is rigidly due to the atoms of such portions of gas. To be more precise, the practical evil in the admission of air to the furnace arises from the presenting a greater number of its atoms to any given number of atoms of gas, in any one locality, or in any given time, than can obtain contact and be chemically united, *on the instant*, with such atoms of gas.

Now, this inequality in the distribution of air, and the destructive cooling influence it creates, cannot be avoided by any plan hitherto adopted; because the orifices of the pipes, conduits, or other means by which air has been made to enter, admit quantities immeasurably greater than can be combined with the small quantities of gas with which they come directly in contact.

Air may be in *excess*, as regards its *effects*, though, as regards *quantity*, it may be *below* the saturating equivalent required by the gas to which it is presented. Its cooling influence will therefore operate, not in proportion to the gross volume introduced, but to the inefficiency of its distribution.

Air may be in excess, and always is so, in the furnace, when introduced in quantities beyond what is due to the surface atoms, or superficial stratum of gas which it *first* approaches. Neither can this evil be remedied by such excess *subsequently* meeting with gas requiring such oxygen or air. The mischief is done by its cooling influence on those atoms which do *not* come into contact, and which, being at once reduced below the temperature of ignition, are paralyzed in their action. Thus, air, when in excess of the absorbing faculty of the gas it encounters, instead of engendering heat, produces cold. The result is, that both are negative, or lost, to the operation of the furnace.

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† "Flame is gaseous matter so highly heated as to be luminous, and that to a degree of temperature beyond the white heat of solid bodies, as is shown by the circumstance that air not luminous will communicate this degree of heat. The temperature of metal, even when white hot, is far below that of flame."—*Sir H. Davy: Researches on Flame.*

The effect of excess or deficiency, then, is not to be judged by relation to the volumes in gross, but to the joint capacities or combining powers of the respective portions of air and gas which meet in collision, and with reference to the relative surface which each presents to the other. On the management, also, of these relative quantities and surfaces will depend the rapidity and simultaneousness of the action, and, consequently, the intensity of the heat evolved; "the heat of flame," as Sir Humphry Davy observes, "being proportional to the rapidity of combustion."

The distinction here pointed out being one of paramount importance, as a further illustration, I have annexed a diagram, (No. 14,) in which the *minimum*, *mean*, and *maximum* effects of surface-contact are brought practically before us. This diagram represents the following sections:

Fig. 1.—Of the flame of a common candle.

Fig. 2.—Of an ordinary single jet of gas.

Fig. 3.—Of a jet from one of the orifices of the furnace diffusion-tubes.

Fig. 4.—Of a jet formed by the blow-pipe.

All these figures are given of the full ordinary size; the atoms of air and gas, however, being necessarily represented of large dimensions, that their respective situations and action may be the more perceptible.

Fig. 1 is the section of the flame of a common candle. The series of circles, *a a*, represents the line of atoms constituting the interior surface, or stratum, of the air endeavouring to obtain contact with the atoms of gas, *g g*, which constitute the exterior surface, or stratum, of the "dark central cone" (see page 104). The intervening space, *p p*, will then be occupied by the atoms from these two surfaces, as they mutually obtain contact and are chemically combining —giving out heat—and forming products of their union. *In this place alone combustion is going on*, forming the "brilliant conical envelope",—properly speaking, *the flame*:* and here we have the *minimum*, or lowest degree of heat.

Fig. 2 represents the flame of a single gas-jet. Here the inner superficial stratum of the air, *a a*, and the outer superficial stratum of the gas, *g g*, are similarly circumstanced to those in fig. 1: the *action* of the air is also the same, which, in both cases, is pressed against the gas with a force equal to the barometrical pressure alone.

Fig. 3 represents a jet from one of the orifices of the diffusion-tubes, as shown in diagram 9: the relative position of the air and gas being now reversed, the air being inside and the gas outside.

Fig. 4 represents a jet occasioned by the action of the blowpipe forced into the body of unconsumed gas collected round the wick of the candle or lamp, the atoms of which are "waiting their turn" to obtain contact with those of the air. Here we have the *maximum* of heat.

Let us now inquire into the causes of the difference in the heating powers of these four states of flame. In fig. 1 we saw, that contact was obtained by the mere pressure of the exterior air against the gas evolved in the interior,—the

* "La flamme n'est jamais lumineuse qu'a sa surface exterieure parce que c'est la seulement que le gaz inflammable est en contact avec l'air ambiant et que la combustion a lieu."—*Pelouze*, p. 462.

relative quantities of each brought into contact being necessarily limited to the extent of their respective surfaces, and the *rate* at which their union is effected; and, since both these were at the *maximum*, the heat given out was also at the *minimum*.

In fig. 2, the action of the atmosphere and the amount of its pressure being the same as in fig. 1, we should naturally infer, that the quantity of gas consumed and heat produced would be the same. That, however, is not the case; for here a new feature is induced, the gas, being *forced* by mechanical pressure against the atmosphere surrounding it, creates, for its own purposes, an additional extent of surface. The result is, an increased measure of contact—of chemical union—and combustion. In this we find the first characteristic of the *jet*, as contradistinguished from the action resulting from mere rarefaction, as seen in the case of the candle. The difference between the quantity of heat evolved by these two descriptions of flame will be as the difference of their contact-surfaces produced in any given unit of time: for in this alone is there any variance. This, then, I call the *mean* heat between the extremes of the candle and the blow-pipe.

In fig. 3 we have an entirely different state of things, demanding special notice. In the last example, (fig. 2,) *the gas-jet* was set in motion *from within*, and impelled, with increased activity, against the *air*, which was *outside* of it. We now reverse this order, by giving the *air* an impulse from *within*, against the *gas* on its *outside*.

As far as mere mixture or diffusion is concerned, we should infer, that the effect would be the same in both cases: namely, that the two gaseous bodies would mingle to the same extent, whether the air were impelled against the gas, or *vice versa;* inasmuch as, the amount of operating influence being the same, like cause would produce like effect.

This, in fact, would be the case, were we merely calculating forces: for, whether A be propelled against B, or B against A, the same amount of *force* is generated and experienced by both; the resistance being equal to the pressure, it being then a case of mere action and reaction.

But, in the case before us, there are other circumstances that require to be taken into consideration besides the mere amount of force. We must take into account the relative *quantities* to be mixed. The diffusion essential to the combustion is, then, not as between A and B, but between A^4 and B: that is, between four atoms of air and one of gas; or, what is still more to the point, ten volumes of air and one of gas.—(See diagram 1.) It thus becomes important to consider which is to be the *moving* body, and which the body to be moved—which is in the active and which in the passive state; inasmuch as we find the quantity of combustion is considerably influenced by this circumstance.

In the case of the candle flame, fig. 1, and the gas-jet, fig. 2, the gas impinges against the air by the force of its ascending faculty alone, or by the mere power of rarefaction; and, meeting the air in its sluggish or inert state, the volume of gas is not able to obtain contact with its equivalent (ten volumes) of air, except to a very limited extent, *until too late;* that is, until one or both have been carried beyond the temperature required for chemical action, and hence the low calorific effect and the great quantity of smoke produced.

If, however, as in fig. 3, we impart to the *air* the impulsive effect, its action becomes accelerated, and we thus increase, practically, the extent of its diffusion and chemical action, up to the point of mutual saturation.

In fig. 4 we have a similar illustration, but more strikingly exemplified, by reason of the increased impulse given to the air, and which compensates for the smaller admission-orifice, as compared with the preceding case.

This impulse, however, in either case, must be judiciously managed, or the gas will be overcharged by the air propelled against it, and a reaction will ensue from the cooling influence of such excess of air.*

Thus we see, that a *smaller* orifice, with an increased impulse, produces a greater effect than a *larger* orifice, with diminished activity in the air. The result merits more attention than can here be given to it.

There are several other circumstances which tend to increase this diffusive influence and its effect; but to go more in detail would be departing from that practical application to which I have endeavoured to confine these observations. Among these, however, may be mentioned a very important class, namely, those arising from the varying temperatures and bulk of the gas or air at the time of contact. This, however, will be considered more appropriately hereafter, as much error exists on this subject among practical men: great attention being paid to the heating the *air* before its admission to the gas, and which is often attended with injurious results; instead of heating the gas before it comes in contact with the air, which would be attended with useful results. Here again we see how the neglect of the chemistry of combustion has led practical men astray in pursuit of an imaginary advantage to the neglect of a real one.

All these favourable circumstances combining in the action of the blow-pipe, we there find the *maximum of heat*, though not *of light*. This distinction, however, not being directly connected with the matter under consideration, to enter on it would be a digression, which would not here be justifiable.

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* "Tant que la quantité d'air qui vient lécher la flamme n'excède pas celle qui est necessaire à la combustion, celle-ci est *accelereé par le courant*, la temperature de la flamme s'élève, et devient plus brilliante, quoique d'une moindre étendue. Mais aussitot que cette limite est dépassée, l'excès d'air sur la flamme s'y échauffe inutilement, lui enléve de la temperature qui lui était propre."—*Pelouze: Traité de l'éclairage au Gaz*, p. 462.

This analysis of the action of the air enables us to comprehend the principle on which these diffusion-jets produce superior heating powers; and we see how closely they are allied to that of the action of the blow-pipe; being, in fact, perfectly analogous in *principle*, and differing only in *degree*. We also here trace the source of the intense heat produced by the action of the blow-pipe. In its flame we perceive, that the whole of the numerous atoms forming the two contiguous surfaces, *a a* and *g g*, are simultaneously encountering their respective equivalents,—entering into chemical union, and producing combustion: in fact, changing electricities. During these several processes the air is in a continuous outward motion, by the force of the pressure or blast impinging on the interior stratum of the cone of gas, and drawing, in the same direction, the heated products of their union. Hence we have a current of accumulating heat and evolved electricity, converging towards a given point, and there concentrating with an intensity proportional to the extent of surface obtained and the rapidity of the current. Thus we have the cause of its *maximum* of heat.*

But there is a feature in all this which must not be overlooked, namely, the relation which these extended surfaces and their mutual action bear upon the question of *time*, for *here lies the source of quantity and intensity*. These latter are, in fact, resolvable into the quantity of effective surface

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* Let us conceive these surfaces, *a* and *g*, within the sphere of chemical or electrical action: *a* charged positively, and *g* negatively; and, further, that the atoms of which they are formed, during the act of changing their electric states, are in a rapid motion, verging towards a common point. We can, then, easily conceive the nature and extent of that concentration which must ensue. In this case, supposing that the inner body formed a stream of oxygen, and the outer one of hydrogen, the latter will give out negative, and the former positive electricity. The results will be found in the products generated by their union, and the intense heat generated by those products.

obtainable in any given unit of time; for *effective surface* is here only another term for *quantity* in the combining atoms; as *time* is but another term for their *effective diffusion and union.*

I have dwelt thus much on this point, because the advantages obtainable from the mode I suggest of introducing air to the gas arise, mainly, from the peculiarities incident to the action of *the jet*, as compared with any other mode of bringing these elements of heat together; these peculiarities being irrespective of the causes which produce them, whether they be the result of the natural indraught, as in the furnace; or of exterior force, as in the blow-pipe.

Turn the matter, then, as we may, the question of perfect or imperfect combustion, as far as human means are to be applied, is one regarding the *air*, rather than the *combustible* —the *mode* in which it may be introduced, rather than the *quantities* supplied—the contact of *atoms* rather than of *masses.*

But why should the practice, at the present day, require that we should have to enforce the necessity for *management* in the introduction and distribution of air to the gas in the furnace, seeing that it is so analogous to the mode now universally recognised in bringing gas to the air in the lamp? Perfect mixing and diffusion being the objects sought, all that science, ingenuity, and experience have established as sound and useful in the one case is equally so in the other: and in the application of skill or judgment in pursuit of this object, it makes no difference whether we speak of bringing *gas to the air*, or *air to the gas.*

From what has been said it will be manifest, that that remedy will be the best in practice which will best enable us to effect the following purposes:

1. Establishing a complete *control* as to *quantity* over the admission of air to the *gaseous* matter in the furnace.

2. Establishing a similar control over the admission of air to the *carbonaceous* or coked portion of the coal resting on the bars.

3. Keeping these two supplies so distinct that they cannot mar each other's functions by influencing the quantity or quality of either.

4. Restricting the supply of air to the ignited carbon on the bars to what is required for its own special process of union and combustion.

5. Accommodating the supplies of air to the *consecutive* character of the several processes which take place in the furnace, by introducing it in the right place.

6. Enabling the air to overcome the impediments to its diffusion among the gases, resulting from their varying *specific gravities*.

7. Preventing any cooling operation in the furnace, by presenting no greater portions of air to any portions of gas than can be chemically combined with such portions respectively.

8. Counteracting the evils arising from the *current* or onward motion of the combustible gases on their being generated, and which current so obstructs their incorporation with the air.

9. Presenting the largest possible *surface*, for mutual contact and diffusion, between the constituent atoms of the gas and those of the air, with the view of compensating for the want of *time*.

10. Ensuring, not merely the introduction of an adequate quantity of air to the gas, but the completion of their *preparatory mixture*, before either has passed beyond the range of the *temperature* required for chemical action.

These several heads will be found to embrace the essentials towards obtaining as great perfection in the process of combustion, and, consequently, as high a calorific effect, as is compatible with the conditions of a furnace.

Let us now see how far the proposed mode will satisfy these desiderata.

The diagrams 9, 10, and 11 will illustrate the principle on which the proposed remedy is founded, as follows:

1. The air is introduced by means of a series of distributors, or diffusion-tubes, with numerous small orifices, through which it will enter, as through a series of jets or blow-pipes. The effect of this will be the obtaining the largest possible extent of contact-surfaces for the air and gas, by which the want of time will be compensated.

2. The air is introduced to the gas from a separate chamber, wholly unconnected with the ashpit (which latter acts the part of an air-chamber, for the carbon on the bars): no interference, therefore, can arise, and no deterioration of the air passing to either can take place.

3. The air, being introduced *in jets*, acquires a force by which it is enabled to penetrate the mass of gases which it encounters in their onward current; thus materially aiding the process of diffusion. This *quasi* process of injection also tends to neutralize the effect of the varying specific gravities of the several gases; the heavy atmospheric air being thus forced among the hydrogen and other lighter gases.

4. These diffusion-tubes are spread over a large surface of the flame-bed. The effect of this is the preventing any excess of heat in any one locality; giving a more available extent of active flame to the boiler, corresponding, in effect, with an enlargement of the furnace. This arrangement, also, accommodates nature in the *consecutive* processes of combination and combustion, as the hydrogen and carbon successively come into action.

In suggesting this mode of effecting the due mixture of the air and gas, I do not affect to say that it is the best for accomplishing the desired purpose. What I do assert is, that I have directed attention to the true causes of the imperfect combustion which at present prevails in our furnaces—to the true principle on which they may be improved—and to the part which chemistry has to act in reforming them.

Before concluding this notice on the *mode* of effecting the combustion of the inflammable gases, I cannot omit adding a few words on some of those recommended by others; namely, such as are founded on the erroneous idea, which appears to have laid hold of the minds of so many inventors of late years, that the gases are *consumable* by being brought into contact with a body of "*glowing incandescent fuel.*" This will be inquired into more in detail when I come to examine the various plans of "smoke-burning" furnaces and boilers. I am here only desirous of checking that misapplication of talent and means which the adoption of this fundamental chemical error induces, and giving them a more correct and useful direction.

The leading condition of the combustion of the inflammable gases being the *mixture* with the oxygen of the air, in *given quantities* and at a *given temperature*, these inventors have, in too many instances, exclusively directed their attention to the latter to the utter neglect of the former. Now, this is unquestionably the condition which demands the least attention at our hands, for though increase of temperature favours the ignition of the gases, not even that of incandescence can effect their combustion.

With respect to the bringing the volatile products of coal (gas, or smoke, or whatever they may be called) into contact with a body of incandescent fuel, the result will be the *reverse* of that on which these patentees have based their pretensions: namely, the *absorption* of heat by their expansion and decomposition, instead of *giving out* heat by their combustion. This fact has long been known, and, in one of Dr. Henry's Papers, (vol. iii.,) read to the Manchester

Philosophical Society, above twenty years ago, he says, "It is a *well-known* property of both the varieties of the carburretted hydrogen, that they *deposit* charcoal (virtually become smoke) when heated; and M. Berthollet has shown, that the amount of this effect is proportionate to the increase of temperature."

This erroneous notion of the supposed combustion of the gases, (or smoke,) by bringing them into contact with a mass of "glowing coals," appears to have originated with Watt; and, having been adopted by Tredgold and others, has since passed into a recognised principle,—thus, by inducing a conventional mode of speaking on the economy of fuel, the error has been perpetuated. It appears strange, that, while so many have taken this as their text, or adopted it as their starting-point, none of these inventors have examined, or even doubted, its correctness. Yet any chemical work of authority would have informed them of the well-established fact, that decomposition, not combustion, is the result of a high temperature applied to the hydro-carbon gases—that no possible degree of heat can consume carbon—and that its combustion is merely produced by, and is, in fact, its *union* with, oxygen, which latter, however, they take little care to provide.

One of the most recent instances of this great practical and chemical error that has come under my notice was exhibited in the plan adopted in some of the London steam-vessels during the last year, 1840. (See diagram 12, No. 1.) In this instance, the gas issuing from the body of fresh coals on *one* set of bars was made to pass *over and among* the body of glowing coals on a *second* set of bars: and this was done under the erroneous expectation that it would thus *be consumed*, and become the instrument of giving out heat. 'Tis strange that such inventors would not first inquire what is meant by being "consumed."

Now, in this contrivance, no attempt whatever is made to bring atmospheric air, *the one thing needful*, into contact with this mass of heated inflammable gas. Indeed, it is manifest, on inspection of the diagram, that there existed no possibility for any approach of air to the gases so evolved. I mention these abortive attempts at combustion as illustrative of the gross errors into which the neglect of the essentials of combustion too often leads ingenious mechanical men.*

The "*combustion of smoke*", indeed, seems to have been the grand desideratum; and the cost of following this *ignis fatuus* is proved by the numerous patents which it has led to, from the days of Watt to the present time. In Newton's *Journal of Arts*,† (August, 1840,) we find one (the last, I trust, of the series) in which the changes are rung on the same theme. (See diagram 12.)

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* "This notable attempt at smoke-burning was made in the supposed pursuance of a patent granted for generating gas in retorts placed above the furnaces of steam-boilers, although it bears no resemblance whatever to such patent. The plan proposed by the patent consisted in placing the fresh coals in iron retorts, from which the gases generated were to pass in contact with the red-hot carbonaceous matter, or coke, produced by the previous charge. On the gases being expelled, the residium, or coke, was to be taken out and placed on the bars of the grate beneath, by which, the gas, from the succeeding charge of the retorts was, in its turn, expected to be consumed. It may here be observed, that this mode of aiding the heat in furnaces is equally unsound in principle as the above with the double set of bars; inasmuch as no means whatever are provided for bringing the air to the gases so generated."—*Patent granted to John Bourne, for "certain Improvements in Steam-engines, and in the Construction of Boilers, Furnaces, and Stoves."*

† "The object of my invention, being the more perfect consumption of smoke and consequent economy in fuel, is effected by such novel arrangement and construction of the furnace, or fire-place, as the first or outermost set of fire-bars is intended to receive the fuel when it is first introduced into the furnace, and the charred or red-hot coal is to be passed backwards, and thus placed upon the second or *moveable* set of fire-bars, and immediately raised by the sliding carriage close to the bottom of the boiler, causing the smoke to come in contact with the charred or red-hot coal, and, as it rises from the green or fresh coal, in the front part of the furnace, *it will be perfectly consumed* in passing over the second, or red-hot fire, instead of being allowed to escape with the gaseous products to the chimney."—*Patent granted to James Drew, for "an Improvement in the Means of Consuming Smoke and Economizing Fuel in Steam-engine and other Furnaces."*

In this patent, the smoke, "as it arises from the green or fresh fuel in the front of one furnace, is to be consumed by the *red-hot fire* of the second furnace." This patentee begins by informing the world, that "the object of his invention is the more perfect *consumption* of smoke." Consumption *(i. e.,* waste) of *coals* would have been a more appropriate title. Yet, here is much ingenuity exercised (as in the cases just mentioned) in ensuring contact with "red-hot fire", which is not called for, or necessary; yet, not one word do we find respecting its union with oxygen or providing a due supply of air; the really and only important condition required.

These patentees, in fact, speak of the combustion of gases, smoke, and vapour as they would of burning a piece of wood by thrusting it into the fire. Yet, chemistry teaches, that heat has nothing to do with their combustion beyond this, that a *certain* temperature is essential to the development of chemical action between the combustible and the supporter, *when both are brought together*. But providing heat is not providing air; neither is decomposition combustion.

In Newton's *Journal*, of February, 1840,* we have another notable instance of the neglect of chemistry, when speaking of combustion. (See diagram 12.) We there have the specification of a patent for "an improved furnace for consuming smoke, and [as a matter of course] economizing fuel." In that patent we have the usual repetition of "the smoke and gases arising from the *combustion* [error first] of a fresh supply of fuel, becoming consumed [error second] by passing over the surface of a glowing fire in the fire-place contiguous" [error third.]

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* "This is effected by dividing the furnace, longitudinally, into two or more parts, in order to form two or more *distinct fire-places*, which are to be supplied with fuel alternately, allowing that in the adjoining fire-place, over which the smoke is to be directed, to have become completely red. The direction of the smoke and gases is regulated by dampers placed at the end of the furnaces, in order that the communication with the flue may be cast off from such fire-place while the fresh fuel is introducing and the smoke emitted is drawn over the red-hot fuel of the next fire-place, through a lateral opening, by which means *the smoke becomes consumed."—Patent granted to Thomas Hall, "for an Improved Furnace for consuming Smoke and economizing Fuel."*

Again: "The smoke and vapour will be compelled to pass through the lateral opening in the partition, *a*, and over the red-hot fuel in the fire-place, A; which smoke and vapour, in their passage, will *necessarily* become consumed, or put in a state of combustion" in the fire-place, B: and, winding up the story, we are told, that "the dense volume of smoke and combustible vapour, evolved at every fresh supply of fuel, may be conducted into the adjoining fire-place, where, by passing over the ignited red-hot fuel, it may become *burnt* and *consumed*"*!* yet, through the whole of this specification also, we have not even a passing notice of the value which air would impart to this ingenious, but lamentably erroneous, smoke and vapour burning process.

Here, as in most of such cases, the use of the "red-hot fuel" in the furnaces is mistaken; and, because red-hot fuel would burn the fingers, it erroneously is supposed capable of burning the gas:—the peculiar use of the red-hot fuel, as regards the gases, being, in fact, not the causing their *combustion*, but their mere *generation* and subsequent decomposition, *preparatory* to combustion, on meeting the due supply of pure air.

These three attempts at combustion which I have here described are all based on the same chemical error, namely, the bringing the gases evolved from a charge of coal on one furnace, or set of bars, in contact with, and to be consumed by, the body of hot glowing coals on another furnace, or set of bars.

I regret having to take unfavourable notice of these inventions; nor would I have done so were it not necessary, in the course of proofs which I had to adduce, that those assumed principles, which are so palpably in opposition to chemistry, should be strongly and broadly pointed out: for, with a like chance of being right or useful, would a man who had never seen a ship, a compass, or the sea give sailing instructions for a voyage, as he who undertakes to give instructions on the mode of effecting combustion, while ignorant of the relation between chemistry and that extraordinary and complicated process.

This neglect of chemistry, when treating of combustion, cannot be too strongly exposed, neither can its study be too much enforced, seeing that it is so practically within the reach of all. For chemistry is no longer the mysterious alchymy of a century ago: it is now a mere rigid inquiry into nature's processes and laws, by the aid of those proofs and illustrations which nature herself has supplied. It has taken its place among the exact sciences, and now recognises no man's dictum or opinion, apart from experimental tests and strict circumstantial evidence.

Looking, then, to chemistry, I would add, in reference to these smoke-burning expedients, that, in seeking to obtain heat from gas, the bringing it into connexion with ignited carbonaceous matter, or to any thing approaching the temperature of *incandesence*, is useless, if not injurious, *until we are assured of having the means of contact with air fully provided for*.

Indeed, the temperature of incandesence, though it will increase the explosive tendency of the gas, and thereby *facilitate* combustion, has yet no natural or chemical relation to the *act* of its combustion; for, while it does nothing in aid of the generation of heat, it risks the loss of the latter by promoting the formation of other and injurious unions in the furnace, if the air be not supplied.

Sir H. Davy has shown, that the combustibility of the gases is increased by increasing their temperature ; but this combustibility implies their union with oxygen. This union, however, is strangely overlooked in the search after mere temperature. Increasing the temperature of the gas, by bringing it into contact with incandescent fuel, can only have the effect of increasing its capability or *faculty* for combustion ; but does not produce or cause combustion. And here I may dilate a little on the various attempts that have been made to heat the *air* previously to its introduction, while no effort is made to heat the *gas*, the value of which has been so distinctly proved, and which is so practicable in the furnace, as will hereafter be shown.

Sir H. Davy observes, that, "by heating strongly gases that burn with difficulty, their continued inflammation becomes easy"; and, further, that "expansion by heat, instead of diminishing their combustibility, (as had been asserted,) on the contrary, enables them to explode at a lower temperature." Enabling them, however, to burn at a lower temperature, or increasing their faculty for combustion, is one thing, while bringing that faculty into action is another and a very different one.

Let us take an illustration on this head from the flame of a candle. The high temperature to which the gas in the centre of the flame is raised considerably increases its inflammability, or faculty of combustion : that such high temperature, however, does not *produce* combustion (as is taken for granted by these inventors) is self-evident.

"This vapour," observes Dr. Thomson, "is raised to such a high temperature, that it combines rapidly with the oxygen of the surrounding atmosphere. The flame of a candle is merely a thin film of white hot vapour, enclosing within it a quantity of hot vapour, which, for want of oxygen, is *incapable of burning*."*

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* "On Heat and Electricity," by Thomas Thomson, M.D. 1840.

Now, this is the whole case against these gas and smoke consumers. For, if high temperature could effect combustion, this little nucleus of gas in the centre of flame of a truly incandescent character would assuredly have been consumed. Yet Dr. Thomson and all other authorities prove it to be "*incapable* of burning."

It is the palpable oversight of this distinction, between increasing the *faculty* of combustion and actually producing such combustion, which has led to that manifest chemical blunder,—the supposing that the coal-gas in a furnace is to be *burned* by the act of bringing it into contact with bodies at a high temperature; or, in the words of the patentees, by "causing it to pass *through*, *over*, or *among* a body of hot, glowing coals." Indeed, these words of Watt, "through, over, or among," have much to answer for: they have led more men astray, and have occasioned more waste of money, loss of time, and misapplication of talent than almost any other false light of the day. The three instances quoted are clearly referable to this source.

In our efforts, then, towards effecting the combustion of the gaseous products of coals, it is essential that we steer clear of this hitherto unquestioned routine; attending mainly to the question of *air*, and all that has reference to its introduction, distribution, and diffusion: for we may take it for granted, that the condition of heat is but a secondary condition; since the required temperature will not be wanting in the furnace, if air be supplied in the proper *quantity*, at the proper *place*, and in the proper *manner*. If these conditions be satisfied, the furnace cannot fail in supplying sufficient heat; and will no more require the aid of a "body of incandescent fuel" than the flame of a candle or the jet of the blow-pipe. If, however, these conditions be not satisfied, an accession of heat cannot remedy the evil, however it may aggravate it.

But, I have said, this erroneous view of the combustion of the gases began with Watt. His patent of 1785 fully justifies this assertion.* In his specification, after reiterating the injunction, that "the smoke or flame is to pass over or through the coked or charred part of the fuel," he sums up in these words: "Lastly, my invention consists in the method of *consuming the smoke and increasing the heat by causing the smoke and flame of fresh fuel to pass through very hot funnels or pipes, or among, through, or near fuel which is intensely hot, and which has ceased to smoke*"; and then follows that part of his instructions which his successors have so strangely neglected, "and by *mixing it with fresh air*, when in these circumstances."

It is clear, Watt had a right conception of the necessity for mixing air with the gas. His error lay in the extent to which he considered the application of heat essential to its combustion. His followers and commentators, Tredgold and others, have neglected that part of his instructions in which he was right—the "mixing with fresh air"; and have fixed their minds on that in which he was wrong—the bringing the gas or smoke "*through*, *over*, or *among* intensely hot fuel."

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* Watt's patent, of 1785, (see Repertory of Arts, vol. iv., p. 226,) consists "in causing the smoke or flame of the fresh fuel to pass, together with a current of fresh air, through, over, or among fuel which has ceased to smoke, or which is converted into coke, charcoal, or cinders, and which is intensely hot, by which the smoke or grosser parts of the flame, by coming close into contact with, or by being brought near unto, the said intensely hot fuel, and by being mixed with the current of fresh or unburnt air, are consumed or converted into heat, or into pure flame, free from smoke. I put this in practice by constructing the fire-place in such a manner that the flame and the air which animates the fire must pass downwards, or laterally, or horizontally through the burning fuel. In some cases, after the flame has passed through the burning fuel, I cause it to pass through a very hot funnel, flue, or oven before it comes to the bottom of the boiler, by which means the smoke is *still more effectually consumed.*" Neglecting the sound, and adopting the unsound, part of Watt's specification, several patents have, of late years, been taken out in the very words of the above. In one of these, by means of double furnaces, one above the other, the gas generated in the upper one is actually forced or drawn down by artificial currents through the ignited fuel in the lower one.

So much, indeed, was Watt impressed with the importance of intense heat that he actually provides both for the "*fresh air*" and *the gas* passing through the hot fuel on the bars; overlooking the facts, that, in that event, the air would no longer remain *pure;* and that no heat to which he could introduce the air or smoke could equal that created in the furnace by the very act of union between the air and the gas; but which he erroneously imagines can be aided by the heat of the "charred part of the fuel."

Thus, we see, the very words of Watt, where he was in error, have been adopted to express the main, and, in many instances, the only, feature of these smoke-burning patents; while the judicious part of his instructions has been unaccountably omitted.

I need only say, chemistry has since taught, that the whole process is either injurious or unnecessary; and that, if the introduction of the *air* be properly managed, the necessary *heat* for effecting combustion will never be wanting in the furnace.

The mere enunciation, then, of a plan for "*consuming smoke*" is *prima facie* evidence, that the inventor has not sufficiently considered the subject *in its chemical relations.* Chemists can understand a plan for the *prevention* of *smoke,* but, as to its *combustion,* it is so unscientific, not to say impossible, (if there be any truth in chemistry,) that such phraseology should be avoided. The popular and conventional phrase, "a furnace burning its own smoke", may be justifiable as conveying an intelligible meaning; but, in a scientific work, or from one professing to teach those who cannot distinguish for themselves, and who may thus be led into error, it is wholly objectionable.

But let justice, however, be done to Watt. It is not his fault that the errors he committed should continue to be repeated: he would have been among the first to benefit by and apply the more correct principles of combustion developed by the rapid improvement of chemical science in subsequent years. My own views of the merit due to Watt, and the injustice done to him and to science by so many of his ill-judged eulogists and followers, have been so ably and eloquently urged by Mr. Parkes, in deprecating this habit of blind submission to rules founded by one set of men on the incomplete experiments and imperfect knowledge of another set that I cannot better express my sentiments than by quoting his words:

"The name, experiments, and practice of Watt are also very commonly used by writers on the steam-engine, as arguments and data for empirical rules which Watt would have been the first to repudiate. This is a system which cannot be too strongly reprobated. It has had the effect of restricting rather than of extending the conquest and realms of science; and much injustice has been done to the character of these distinguished men by the excessive zeal of disciples. Smeaton and Watt were not merely engineers: they were great *practical philosophers*. Their career was marked by a succession of bounds over mechanical obstacles. Their writings exhibit a modesty becoming greatness; and, in giving to the world an account of their experiments and discoveries, they never dreamed that they could be regarded as laws to control future ages, or be viewed otherwise than as progressive steps towards the attainment of a perfection in their favourite pursuits, which, they well knew, neither the life nor labours of any single man (however great his genius) could accomplish."—*Parkes on Boilers and Steam Engines.* Trans. Inst. C. E. Vol. iii., Part 1, p. 24.

SECTION VIII.

OF THE PLACE FOR THE INTRODUCTION OF AIR INTO THE FURNACE.

THE last consideration of the series, regarding the introduction of air to the furnace, has reference to the *place* or situation where it may act its part with the greatest effect in aid of the means by which nature works out her own ends in the process of combustion.

From what has been said, it will be manifest, that the situation to be selected should not only be such as will favour its coming most advantageously into contact with the combustibles with which it is to unite, in their respective states of solid and gaseous, but that it shall not interfere with any other of the processes going on in the furnace: otherwise, we risk the counteracting in one direction the good we do in another.

These considerations are generally overlooked in practice, and the whole summed up in one indiscriminating, general rule, as expressed by Tredgold, namely, " that, in order that *perfect combustion*, or burning of the fuel, may take place, the air should have *free access* to every part of the fuel which is heated sufficiently to burn." Here there is no discrimination between the gaseous and the solid, and no reference to quantity of air or any other condition of "perfect combustion." This loose mode of expression, particularly when it conveys erroneous principles, is highly reprehensible. Such *dicta* from such quarters pass current, and, becoming fixed in the minds of youth, present great obstacles to the introduction of truth.* We meet with no such inaccuracies in the works of our best chemical authors. Unfortunately, mechanical engineers look less into chemical authorities than is consistent with the science they profess and their real interests.

I assert, in contradiction, that "*free access*" should not be given *to any part* of the fuel in *any stage* of burning, and that such is incompatible with "perfect combustion."

The first consideration, then, arising out of the several states of the combustibles, is, that there be, at least, *two distinct* places for the admission of the air, and that these be so situated that they be susceptible of separate control.

Of the place for admitting air to the *solid carbon* on the bars, it is manifest we have no alternative; for, even if we had a more practical, it does not appear that any more judicious, place could be selected than directly from the ashpit upwards towards the bars and the fuel upon them; yet, a patent has actually been recently taken out for reversing this order. This arrangement, indeed, cannot, *as to place*, be improved, inasmuch as the carbonized fuel, being spread on the bars, with an extended surface for the air to act on, presents the most favourable means of bringing both together: it being here particularly to be observed, that no greater quantity of air should be allowed to enter, in this direction, than what is strictly applicable, and required for the union with and combustion of the *carbonized portion* of the coal.

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* To this general rule is added the following incomprehensible and, from a scientific man, unpardonably careless and erroneous note:

"Perfect combustion of the fuel is to be understood only so far as it is consistent with obtaining the greatest degree of useful effect. It must never be pushed to that point when the gaseous products, and the air necessary *to blow the fire*, consume more heat than the fuel generates."

How "perfect combustion" is to merge into this state of imperfection is unintelligible; and the idea of perfect combustion being "pushed too far", so as to cause more heat to be consumed than it generates, is a chemical novelty. Again, how the "gaseous products" are to *consume* air or heat is equally unintelligible. The quantity of air necessary to "blow the fire" must be for others to discover. "Perfect combustion" being only consistent with the "greatest degree of useful effect" is only another mode of saying it is to be consistent with itself.

That portion, however, of the air which is intended for *the gas* must be supplied from some other quarter, and requires another arrangement; for, as we have been warned, when treating of the *quality* of the air, the channel *by the ashpit and bars* is the most objectionable that could be selected, inasmuch as it cannot reach the gas, in that direction, without, first, urging, unduly, and in the way of blast, the combustion of this carbonized matter, and, secondly, without undergoing manifest deterioration and loss of oxygen.

Tredgold contemplated introducing the *entire supply* of air through the ashpit and bars; and in the description attached to the plates of boilers and furnaces, in his work on "Ventilation," (lately republished,) this is put so distinctly that it cannot be misunderstood: "The gas which distils from the fresh fuel having to pass over the red-hot embers, *through which the air from the ashpit ascends*, will be inflamed," &c. Here we have the old error, namely, supposing that passing the gas over red-hot fuel is the means by which its combustion is to be effected.

Mr. Parkes was the first, I believe, who suggested and adopted, in his patent of 1820, a separate supply of air to the gases, selecting the bridge as the locality. If the air is to be introduced in a mass, or in any one locality, then the hollow bridge of Mr. Parkes is unquestionably the most suitable; because, the greatest body of heat being there collected, the effect of its cooling influence would be attended with, comparatively, the least diminution of complete combustion. But it has been already shown, that the required supply of air is, necessarily, so great that it precludes the possibility of its being introduced, at any one place, or through any few orifices, wherever they may be situated, without manifest danger from their cooling influence, even though such air should previously have been heated,* and without producing an unequal and injurious effect on the contiguous portion of the boiler.

In what place, then, should the air be admitted? This can only be answered by reference to the chemical conditions under which it combines with the gas; namely, those of quantity—preparatory mixture or diffusion—and temperature. For obvious reasons, these conditions cannot be satisfied at the bridge, or in front of it.† We are thus reduced to the alternative, that, as the air to the carbonized fuel on the bars must come from the ashpit, that to the gas will be best introduced beyond the bridge.

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* An improved modification of the hollow bridge has been, for many years, adopted, on the suggestion of Mr. Shaw, in the vessels of the Dublin Steam Company. By this arrangement the air is introduced, not by a hollow bridge, as has been tried unsuccessfully, but in front of the bridge: a fire tile or brick shield being placed on the bars to prevent access of the air to the incandescent fuel on them. These have been found the most practically useful of any hitherto adopted. The details of these kinds of bridges will be given hereafter, with their relative effects.

† "When air is admitted in front of the furnace, or through, or over the fuel, it obviously never can effect those useful purposes which are, at once, obtained by admitting it in due proportion to the intensely-heated inflammable vapours and gases; or, in other words, to the products of the distillation of coal, at such temperature that they may take fire in its contact. In this way each jet of air which you admit becomes, as it were, the source or centre of a separate flame; and the effect is exactly that of so many jets of inflammable or coal gas ignited in the air: only, in your furnace, you invert this ordinary state of things, and use a jet of air thrown into an atmosphere of inflammable gas; thus making an experiment upon a large and practical, which I have often made on a small and theoretical, scale, in illustration of the inaccuracy of the common terms of '*combustible*' and '*supporter of combustion*', as ordinarily applied.

Looking chemically at the constitution and combustion of gaseous bodies, the only advantage which the locality of the bridge presents is the securing one of those conditions alluded to, namely, the required *temperature.* This, however, it has been already shown, demands the least attention on our part, though unaccountably considered as the only one necessary, and from which so many of the errors of the present practice have originated.

Were it possible to maintain a continuous high temperature at a distance from the bridge, or a chain of igniting points or stations, the most effective mode of introducing air would be by a corresponding succession of jets along the flues, (due regard being had to the entire quantity required,) thus feeding, as it were, the stream of gas through the line of its flight, and producing a continuity of combustion, or body of flame; avoiding an extreme of heat in any one place, or a deficiency in another, until the last atom of gas had been supplied with oxygen, fired, and chemically consumed.

And, if we consider what an enormous mass of gas is to be ignited and of flame produced, from a single ton of coals,

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"I fill a bladder with coal-gas, and attach to it a jet, by which I burn a flame of that gas in an atmosphere of, or a bell-glass filled with, oxygen: of course, the gas burns brilliantly, and we call the gas the combustible, and the oxygen the supporter of combustion. If I now invert this common order of things, and fill the bladder with oxygen, and the bell-glass with coal-gas, I find that the jet of *oxygen* may be inflamed in the atmosphere of *coal-gas* with exactly the same general phenomena as when the jet of *coal-gas* is inflamed in the atmosphere of *oxygen.* This is precisely your process. You admit a number of jets of air into a heated, inflammable atmosphere, and so attain its combustion in such a way as to produce a great increase of heat; and, as a necessary consequence, destroy the smoke. You, in fact, convert what is commonly called smoke into fuel, at the *time when*, and the *place where*, this combustion can be most effectively brought about."—*Mr. Brande's Letter to the Author* (supposing that all were consumed equally well, as in the Argand lamp or jet of gas light,) the inconvenience of having its actual combustion confined to one locality will be the more apparent.*

As, however, we have not discovered the means of maintaining such a succession of gas-igniting points or stations as is here supposed, we must manage to extend the orifices for the introduction of the air along the flame-bed to afford time and space for diffusion; limiting the extent to the means of maintaining it unextinguished, until the whole of the gas has passed through its successive changes of preparation, ignition, and combustion.

With respect to the *length of flame* obtained in a furnace, under the present system, Tredgold considers six feet from the bridge as the maximum available length, and which, he infers, should have direct reference to the length and shape of the boiler.* This assertion is evidently founded on the supposition, that there is no necessary preparatory process, and that these six feet may be considered as the distance which actual flame traverses before its constituents are, as it were, *burnt out*, or exhausted. This view of the nature of flame, however, is not supported by any chemical reasoning.

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* One ton of coals produces 10,000 cubic feet of purified gas. These require ten times their volume of atmospheric air; say 100,000 cubic feet—making, when duly incorporated, 110,000 cubic feet of explosive mixture, and which, when fired, would produce a full volume of intensely hot flame to that extent; and without adding any thing for that expansion which accompanies the act of combustion.

Now, supposing this enormous mass of flame, or ignited gaseous matter, passing through the orifice or throat of a furnace one foot wide and one foot high, (one foot square,) it would extend to a distance of no less than *twenty and three quarters miles*. Were we to take into account the flame from the tar, oils, and other combustibles, which are also volatilized in the furnace, through separated in the purificators of the gas works; and add, also, the proportion of air due to the combustion of the bi-carburetted hydrogen or olefiant gas, which is always present to the amount of from ten to twenty per cent. in coal-gas, we see the volume of flame here described would be considerably enlarged.

Of the heating powers of such explosive mixture we cannot have a better illustration than this, that, when we fire, in the laboratory, a single cubic foot of these 110,000 cubic feet, the heat and explosive effect are considerable.

Thus we see, that, though the loss of a few thousand feet of these 10,000 may not be considered an important consideration, yet the loss of a corresponding portion of this 110,000 cubic feet of inflammable mixture is not to be contemplated without showing us the extent of our loss. The question, then, is, not what portion of the 10,000 we lose, but what portion of the 110,000 we have converted into active flame for the purposes of the furnace and boiler.

But let us inquire what causes these six feet, or any number of feet. " Perfect combustion" (which Tredgold would instruct us to effect) would give no *length* of flame whatever, and no smoke. It would, in fact, be *explosive*, as we witness it in the laboratory; for by no arrangement can we give *length* to flame, after having once effected the mixture of the combustible and the supporter at the required temperature.

If, then, the *length* which flame exhibits in the furnace has, or ought to have, any practical connexion with the size or shape of the boiler, it would be important to inquire how it could be promoted or extended. But mere *length* of flame has already been shown (when speaking of the Argand lamp, page 109) to be direct evidence, that the process of mixing the air and the gas, preparatory to ignition, has been incomplete, by reason of a deficiency of points of mutual available contact and sufficient time; this continuousness, or apparent length in flame, being, in fact, the measure, or in the ratio, of the time during which—not the *combustion*, but the preparatory *diffusion* is going on.

For we have no chemical reason or ground for supposing that flame is or should be *continuous*, or have *length*, or even *existence*, at any distance from the point where its ignition commenced, beyond what is due to expansion alone. In fact, length, or continuity of action, is inconsistent with the nature of gaseous bodies, or their chemical combinations.

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* " The distance to which the *flame* and *heated smoke* of a fire will extend, *so as to be effectual*, will depend on the draught of the chimney and the nature of the fuel: from three to six feet will be about the range in a well constructed fire-place; that is, about six feet with coals and a good draught, and about three feet with coke and very slow draught. This, of course, will regulate the length of the boiler."—*Tredgold on Ventilation.* 1836.

Apparent length, then, as I will term it, must be considered as indicative of the *succession* of new atoms or sections of the combustible entering into combination; that is, of a *consecutive* process; and not of the time actually required to complete the combustion of any such atom or section. This view of the nature of flame has an important bearing on its practical efficiency in the flues of a furnace, and shows us, that our attention should be directed to the promoting this *consecutive* character, or series of *perfect* combustions, with their rapid combinations, as shown in the flame of the Argand lamp, see fig. 46; rather than as in fig. 48, with its *lengthened* flame and *imperfect* combustion.*

From this reasoning we are led to conclude, that where flame assumes a prolonged or lengthened appearance, as in the case of the candle, or even of the greatest conflagration, it is solely in consequence of the atoms of the liberated combustible gases being, by some cause or other, impeded in effecting mechanical contact and diffusion with the atoms of the air; and having to "*wait their turn*" in effecting their respective mixing and firing; and not of any time being required for actual combustion, to which the evidence of facts and the illustrations of chemistry are repugnant.

Were we assured, that, in these "six feet" of Tredgold, the entire of the constituents of the gas were adequately incorporated with the air and consumed, no further inquiry would be requisite, and we might rest satisfied that combustion was complete. But the very existence of the "heated visible smoke" is proof to the contrary, and we know not how much *invisible* heated smoke may accompany it.

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* This is shown by the fact, that, in some cases, on closing the air-admission orifice, *b*, diagram No. 9, the flame assumes a lengthened appearance, similar to that exhibited on closing the orifice for admitting air to the gas in the interior of the Argand lamp, see fig. 48, page 109. Now, it is clear, that we are not justified in supposing that this enlargement of the apparent volume of flame in the furnace flue is indicative of a more effective combustion. The reverse, we see, is proved in the Argand lamp, where length of flame is the *opposite* of quantity, or intensity, either as to heat or light.

But "the distance," says Tredgold, "to which the flame and heated smoke will extend, so as to be effectual, will depend on the *draught* of the chimney"; and this, again, is to "regulate the *length of the bottom of the boiler*." This view of the cause of the length of flame is quite erroneous, and the inference is a great practical error. This length of flame, perceptible in the furnace, depends on the rapidity with which the essentials to combustion are satisfied, and the process completed; and when these are satisfied, the shorter the flame, the greater will be the heat obtained, because the act of chemical union will be the more rapid and intense. So far as the draught is concerned, it has no natural or chemical reference to the "length of the bottom of the boiler." When the draught is operative in producing perfect combustion, it tends to *shorten*, rather than *extend*, the flame.

But assertions of this kind have rendered it necessary that we should thus examine into the causes, chemically considered, of the length of flame. Length of flame, then, is not, in all cases, to be regarded as a *good*, from which advantage may be derived; it may even be an *evil*, which should be avoided. It is visible proof, that *perfect* combustion is inconsistent with *length;* and that our object will be best attained in the furnace by a succession of flames, or jets of flame, with *perfect* combustion, rather than by the *length* of any one mass of flame, which we have seen is the accompaniment of *imperfect* combustion,

With these considerations I refer to the diagrams Nos. 9, 10, 11, and 13, for some of the modes by which our purpose may be effected. Any modification of the plans here suggested will answer, provided the *principle* be carried out, of introducing the air by way of *jets*, or various apertures, and securing adequate time or contact for diffusion.

I conclude these observations as I begun, by stating, that I lay no claim to discovery or invention, or to any new view of the nature of combustion. I have merely sought to give the science of chemistry a more enlarged and practical application,—to enforce attention to the indispensable connexion between chemistry and the operations of the furnace,—and to the labyrinth of errors in which we inevitably become involved when we neglect its precepts or deviate from its laws.

If any dispute my chemical details or illustrations, I shall not fight the battle with objectors, but refer to my authorities. On this head, though I might have enlarged my means of defence, I could not have added to the strength of my position. I have already a host in those whose principles I have endeavoured to enforce, and the value of whose aid I have sought to extend to practical contemporaries in the same field. Among those I have consulted or quoted are, Sir Humphry Davy; Dr. Faraday and Professor Brande, both of the Royal Institution; Professor Daniell, King's College; Professor Graham, University College; Dr. Thomson, University of Glasgow; Dr. Reid, University of Edinburgh; Dr. Robert Kane, of the Royal Dublin Society; Professor Kelland, of Cambridge (now of Edinburgh); Dr. Ure; Dr. Henry; Dr. Brett, of the Royal Institution, Liverpool; and Dr. Dalton, of Manchester. Among the Continental authorities are, Berzelius, Dumas, Chevreul, Pelouze, Berthier, Persoz, Berthollet, Thenard, and Leibig. I have taken these as my guides, and am not aware that I have urged any thing in opposition to those standard authorities of the present day.

POSTSCRIPT.

OBSERVATIONS ON THE MODES OF APPLYING THE FOREGOING PRINCIPLES TO PRACTICE.

Having made several practical applications of the chemical principles referred to in this treatise, I avail myself of this opportunity to make some observations on the results obtained, and to draw some general inferences from these results, although in anticipation of what more properly belongs to the second part of this work.

I have applied these principles, and the means suggested for effecting diffusion between the gas and the air, in a great variety of forms, and in furnaces of different descriptions, as applicable to stoves and kilns, marine and land engine boilers. The use of hot air, also, a point to which inventors have turned their attention, I have tested in a variety of ways. In some cases, the air has been raised to a high temperature, and in others it has been so introduced that it must necessarily have been cold when brought into contact with the gases. In both, however, complete combustion appeared equally attainable.

As the relative advantages of hot and cold air will be considered more in [illegible] will here only observe, that, if any general proposition were now to be hazarded, the experience derived from numerous and varied trials, under steam-engine boilers, justifies the use of *cold* rather than of *hot* air; and proves, that, in the arrangements of our furnaces, attention should rather be directed to raising the temperature of the *gas* to be burned, than of the *air* which is to effect its combustion, previously to the two coming into contact.

This view of the subject is also in accordance with what our every-day experience suggests; a great difference being perceptible in favour of the completeness of the process of combustion, and in the heat obtained in the furnace, when the atmosphere is *coldest*, and even at the lowest temperature, in frosty weather.

The idea of an increased value from the use of heated air in our boiler furnaces appears to have grown out of its adoption, in what is called the *hot blast*, in the manufacture and working of iron. The cases, however, are quite dissimilar; and when alleged advantages have been attributed to the introduction of heated air, I have generally found that those advantages were, in fact, derivable from other causes not noticed by the operators.

In diagram No. 9 is represented an ordinary land-engine boiler, with vertical tubes, placed above a chamber to which the air is introduced from any convenient situation. The only consideration being, that it be made to act independently of the current to the bars—the pipes or conduits for its introduction may be placed in any part of the ashpit, or through the water in the boiler, or through the adjoining brick work. In this plan, the gases, passing over the bridge, come directly into contact with the jets of air issuing from the orifices of the diffusion-tubes.

In diagram No. 10 is represented a marine boiler and furnace, in which, from the contracted dimensions of the flues, a different arrangement becomes necessary. In such cases the vertical tubes might interfere with the free passage of the gases and flame, and obstruct the entrance for the purposes of cleaning and repairing.

The arrangement shown in this diagram consists of a series of perforated diffusion-plates, placed at an angle of about forty-five degrees, and extending from the bridge to any required distance in the flues. A space is here left on each side of these plates, (as shown in section, fig. 2,) in which the dust and ashes collect, without obstructing the orifices of the plates. Both these arrangements ensure a full combustion of the gases, where the size of the flues is sufficiently large to admit of their introduction without checking the draught.

In diagram No. 11, fig. 1, the air is introduced from a chamber to the outsides of a series of horizontal perforated tubes, through the orifices of which it passes *inwardly*, and thus its contact is obtained with the evolved gases in their current through such tubes. The result of this arrangement is rapid and complete combustion.*

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* In the *Inventors' Advocate*, No. 86, a description is given of a patent granted to Charles Delbruck, for "*improvements in apparatus for applying combustible gas to the purposes of heat*", and which contains the following notice of the mode adopted, of the efficacy of which I have no doubt, from the application of the principle of the jets of air.

"Claim Second.—The mode of constructing apparatus for consuming gas, thus applying it to the purposes of producing heat, by causing a *series of jets of air* to be propelled against, or near, a flame of gas.

"This apparatus consists of a chamber, through which a pipe, perforated with holes, passes. Gas is, at first, introduced into the chamber, and lighted, when it will burn with a soft flame; but, *on the air being admitted through holes in the pipe*, it will cause it to burn in jets of flame, and the heat will be much increased.

"Claim Third.—The mode of *introducing jets of air into a tube through which the inflammable gas is passing*. The air is admitted into the flame of the gas in a similar manner to that above described. The patentee prefers using carburetted hydrogen when cheapness is considered, and pure hydrogen when great intensity of heat is required."

Here we have an exact description of the plan above proposed for a furnace, "introducing jets of air into a tube through which the inflammable gas is passing."

This plan is well adapted to stoves, kilns, and furnaces for chemical and other purposes, where large volumes of combustible gases are generated, and where a great and uniform heat is required.

In fig. 2 of the same diagram the air-tube is placed at the bottom of the chamber, where the air must, necessarily, be at the lowest temperature when coming into contact with the gases. Complete combustion is, notwithstanding, here also obtained. This mode has been found to answer the desired purpose where the evolved gases are not too copious, or the draught so rapid as to carry them onward into the flues before diffusion is effected.

The appearance and character of the flame, in these two opposite cases of quick and slow diffusion, are so remarkable, and so different, as to merit a particular notice. In the first, fig. 1, the air passes from the outside of the tubes to the gases within them; while, in the second, fig. 2, it passes from the inside to the gases without. In fig. 1, the air coming into collision with the heated gases in the interior of the tubes, contact and diffusion are instantaneously effected by the impinging force of the jet: no atom of gas escaping its equivalent of air. In this case, the flame and products of combustion issuing in fierce currents from the several tubes, perfect diffusion seems to be effected on the instant of contact, as in the Patent *Solar* Argand Lamp, to which, in principle, it bears a striking analogy.

The rapidity with which diffusion and combustion are here produced presents an illustration of the fact dwelt on by Sir Humphry Davy, in his "Researches on Flame", namely, the increased combustibility of the hydro-carbon gases when raised to a high temperature, (see page 132,) since they must necessarily become much heated in their passage through the hot diffusion-tubes.

An important advantage in this latter arrangement is, the means it affords of effecting diffusion of large bodies of the gases generated in furnaces with very large fires, within the proper time: that is, before the current has carried those gases into the cold region of the flues, by which they would be converted into smoke.

In fig. 2 we have a different effect and character of flame exhibited. Here the evolved gases, passing over the bridge, are projected downwards, and come into contact with the air as already described. In this case, the act of contact not being so sudden, as in fig. 1, more time is obtained, and complete diffusion and combustion equally effected. Here the visible, that is, the carbonaceous, part of the flame appears to float, in soft, wave-like volumes, as an upper stratum in this diffusion-chamber, presenting the beautiful appearance of what is called the *fire-cloud;* the body of the chamber being, at the same time, filled with the products of combustion, clear and transparent. On stopping the admission of air, however, the chamber instantly fills with a dark cloud of smoke and unburned gases, as it would be in an ordinarily constructed furnace.

The flame, in the latter case, does not assume the fierce projectile character it did in the former. Combustion, however, being equally complete, the flues present the same intensity of heat, as indicated by the thermometer; a fact that would not appear probable from the different characters of the two flames.

By the process of mixing adopted in this latter furnace, we are enabled to distinguish the peculiar flame arising from the combustion of the *carbonic oxide:* a combustible gas which is copiously produced when the fuel on the bars becomes highly ignited and of a bright red. (See page 64.) "This mode of supplying atmospheric oxygen," observes Dr. Ure, "prevents the possibility of the carbon of the coals escaping in the state of carbonic oxide gas, whereby, at present, much heat is lost in our great furnaces."

The peculiar colour and character of this gas, in combustion, is here very distinguishable. Without diffusion, however, this carbonic oxide gas, at a temperature sufficiently high for its ignition, (and which is considerably lower than that required by the carburetted hydrogen gas,) would escape by the chimney, to be consumed at its summit on meeting the air.* The importance of converting this gas to the purposes of heat, or even its existence in the furnace as a combustible, is wholly overlooked by engineers.

In fig. 3 of the same diagram (No. 11) is given another illustration of a similar process on the introduction of cold air. The chamber into which the air is introduced is here placed at the back of the bridge and in the coldest part, where no heating influence could reach it. This diffusion-plate is perforated, and the jets of air come into contact with the gases as they are projected downwards, presenting, in other respects, exactly similar appearances to those described in the last example.

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* Dr. Kane, in his letter to the author, observes, "The formation of carbonic oxide, to which I find, in your work, for the first time, the attention of practical men directed, is a source of loss of fuel to a very considerable extent. When carbonic acid streams over a surface of ignited charcoal or coke, it cannot be considered to evolve heat in taking up an additional equivalent of carbon. This is verified by the fact, that the *carbonic oxide* thus formed gives out, in burning, only the same quantity of heat which the second equivalent of carbon should have given out, if it formed *carbonic acid directly*. This heat you economize, and hence, even at those periods when carbonic oxide is produced, you lose no fuel; whilst, on all the ordinary plans of avoiding visible smoke, the fuel is evolved as carbonic oxide, and is either silently lost, escaping in invisible gas, or burns at the orifice of the chimney, wasting there the carbon which should have been economized below."

Dr. Brett, on the same subject, adds, "Every one who observes the volumes of black smoke escaping from the chimneys of manufactories must be struck with the positive loss of fuel thus sustained; yet, not only is the black smoke lost for calorific effect, but a further loss may be traced to the passing off of what may be called a smoke, though not visible—I mean unburnt carburetted hydrogen and *carbonic oxide*.

"On one occasion, whilst watching the process of combustion, during its different stages, in your experimental furnace, at that period when the hydrocarbons had just undergone combustion, and the carbonaceous matter, or coke, was remaining on the fire-bars, highly ignited, I observed, when looking into the flue, the phenomenon of a peach-coloured flame mingled with one of a striking blue colour. The former I believe to have been produced by the burning of cyanogen: the latter was undoubtedly due to *carbonic oxide*. I need hardly say, that, without a proper supply of atmospheric air, these gases would have escaped by the chimney, and so have been lost for calorific purposes."

Diagram No. 13 shows other modes of introducing air to the gases to be consumed. Fig. 1 represents the front of a marine boiler in which the air-admission tubes are described in different situations. In section 1 the tube is placed at the bottom of the ashpit; in section 2 it is placed in the centre of and *passes through* the ashpit air-distributor; in sections 3 and 4 the tubes are placed one *on each side*, and corresponding with the bars; in sections 5 and 6 they are shown as passing *through the water-ways* in the boiler: in all cases entering the chamber behind the bridge.

Fig. 2 of this diagram represents a section of a reverberatory or other furnace, where flame and heat, free from smoke, are essential. In this the air-tubes are placed between the bridge and the flame-bed, their number being proportioned to the size of the furnace. Here the air is represented as passing from the outside to the gases within them, as already described in diagram 11. A cross section of this furnace is also here shown.

Fig. 3 (same diagram) represents a cross section of a furnace or stove for heating iron plates. In this plan, the air-diffusion plates form the crown of the arch, the jets issuing downwards against the gases as they pass from the furnace over the plates or other body to be heated.

The whole of these varied practical illustrations prove, first, the absolute necessity for *atomic diffusion* between the gas and the air before they have passed into the flues and are cooled below the temperature required for chemical action; and, secondly, that, if such diffusion be accomplished in the proper time, it appears unimportant in what precise manner or part of the flue it is effected; or whether it be by a quicker contact and action, as in fig. 1, (diagram No. 11,) or by the slower one, with the compensating power of *time*, in a larger chamber, as shown in figs. 2 and 3.

Effecting *diffusion* at the *proper temperature* being the main object, the circumstances of large furnaces, from the necessarily large volume of air required, would seem unfriendly to this operation, the cooling influences of so much air producing smoke before adequate diffusion has been effected.*

A remedy for the evil may be had by dividing large furnaces into two portions by an internal partition, thus providing for *alternate* charging, by which means the volume of gas evolved, and the consequent demand for air, will be reduced to manageable quantities in each.

In large furnaces the greatest obstacle to the *absolute* freedom from smoke arises from the irregularity in the time and mode of charging, and the consequent inequality in the quantities of gas generated—of heat in the body of the furnace, and of fuel on the bars. These considerations naturally suggest the great importance of supplying furnaces in a more regular and *uniform* manner. This, however, can be done only by *mechanical* means, several plans for which are already before the public. The value of mechanical agency, in this respect, will be more fully considered in the second part of this work, where I propose introducing a remedy for the above evils. Until some plan of this kind be adopted, such is the irregularity with which furnaces are charged, and such the variable quantity of gas generated and air supplied, that we must not expect to see chimneys entirely free from smoke: much of this smoke, however, may be attributed to the *steam* generated by combustion, as it must not be forgotten, that one half the atmospheric oxygen employed in combustion is converted into steam, (see diagram No. 1,) which in high chimney shafts is so reduced in temperature as to be visible on its exit.

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* "Smoke is the result of the imperfect combustion of the volatile products, in consequence of their being mixed with either too small or too large a proportion of atmospheric air. Either of these circumstances, that is, too little air with a high, or too much air with a low temperature, causes the separation of the carbon from the hydrogen, and the consequent change of the carbon from the colourless state of gaseous combination into a black pulverulent form.

"The carburetted hydrogen gases require, as the condition of their combustion, first, that they be *intimately blended* with an appropriate volume of atmospheric air; and, secondly, that the mixture be heated to the temperature of accension. The unignited gaseous mixture, in travelling through the flues, loses temperature very fast, and deposits the eliminated carbon in the form of sooty smoke."—*Extract from the Specification of the Author's Patent, as revised by Dr. Ure.*

I may here remark, such is the great variety which prevails in the arrangements of boilers and the several kinds of furnaces as at present constructed; so different are they in size, length, and description of flues; in proportions of fire-surface and flues; force of draught; and other circumstances, all of which have more or less influence, that some judgment is required in adapting the true chemical principles of combustion to practical operations on a large scale. Engineers, therefore, should not expect that they will obtain the desired object without a due consideration of these points.

I here repeat, what I stated at the beginning of this treatise, that, in suggesting these modes of effecting combustion of the gases, "I do not affect to say, that they are the best for accomplishing the desired purpose: what I do assert is, that I have directed attention to the causes of the imperfect combustion which at present prevails in our furnaces: to the true principles on which they may be improved: and to the part which chemistry has to act in reforming them." Difficulties will occasionally present themselves in bringing practice to harmonize with science; being, however, once set on the right road, the ingenuity and talent of the present day are fully adequate to supply what may be wanting.

Throughout this work my object has been to place the inquiry on a right footing: to show that all that belongs to the combustion of fuel results from chemical considerations, and can only be explained and improved by means which are in strict conformity with chemical principles. Above all, I have been desirous of enabling those who are connected with the manufactures of this country and with steam navigation to judge for themselves, and thus take them out of the hands of "*quacks*", as Professor Brande justly designates those who, rejecting the aid of science, would discourage all improvement unless it square with those empirical and absurd *dicta* which we find laid down as "unerring rules", and dignified with the name of "*practice.*"*

RECAPITULATION.

In conclusion, I would here briefly recapitulate the leading points to which it is desirable that attention should be directed.

First: The combustible constituents of coal are *hydrogen* and *carbon;* the former being the chief ingredient in the formation of the *gaseous* portion, which is expelled on the application of heat; the latter, of the *solid* portion, which remains on the bars after the gases have been separated, forming the cinder or coke.

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*. "It unfortunately so happens, that, when *scientific* men urge new views, or suggest the practical adoption of rational theories, they are neglected, because it is presumed they are merely founded on unsubstantial hypotheses; and, on the other hand, when *practical* men attempt to found improvement on scientific principles, they are sneered at as dabblers in science; and so both become disheartened and disgusted, and the only people who are temporarily successful are *quacks*, who, pretending to what is called originality, and neither referring to practice nor science, steal from both; but, deficient in all knowledge of their own, ultimately mislead their followers; and, like the alchemists of old, not unfrequently deceive themselves."

Secondly: On a charge of coals being thrown on a furnace, the hydrogen, and a portion of the carbon, are separated in the form of a gas (carburetted hydrogen.) This gas, escaping from the furnace over the bridge the instant it is produced, cannot be retained by reason of its gaseous or volatile character; and of the draught, or onward current; and hence the great practical difficulty of effecting its combustion.

Thirdly: We have to consider the conditions of the combustion of these two distinct bodies, namely, the *gaseous* and the *solid:* the one requiring to be consumed during its flight from the furnace, in the *flues;* the other, in a solid state on the *bars.*

Fourthly: This double act of combustion, or, rather, the combustion of these two different bodies, involves two distinct chemical processes, and, consequently, the providing of two distinct supplies of air, to be brought into action in two distinct places. This is the first and great practical essential in our endeavour so to consume the coal that *all* its combustible constituents shall be converted to the purposes of heat.

Fifthly: The separate quantities of air required for these two processes must be regulated on strict chemical principles. If *less* air be supplied to the gas than its proper equivalent, a proportionate quantity of the latter must escape uncombined, unconsumed, and useless. If *more* than that equivalent, the excess is injurious from its cooling influence, and the body of heat which such excess necessarily absorbs and carries away.

Sixthly: This proper quantity or "equivalent" of air being supplied to the gases, the next point for consideration is their *diffusion,* that is, the effecting their *atomic* mixture. This is the most difficult, as it is the most essential, and, hitherto, most neglected, part of the operation, and as it involves the considerations of time, place, and temperature;

seeing that the chemical action and union, which we call combustion, will not take place unless at a certain high temperature.

Seventhly: In effecting *practical diffusion* in the furnace, the greatest amount of mutual contact surface between the respective atoms to be mixed will be obtained by means of jets: on which, therefore, depends much of the rapidity and completeness of the process.

Eighthly: We have thus to consider:

1. The generation of the gases, and the cooling operation of that process.
2. The conditions of their combustion, as distinct from that of carbon on the bars.
3. Obtaining the due quantity of air essential to the combustion of these gases.
4. Keeping this supply of air apart from the air entering to the carbon on the bars.
5. Introducing the air intended for the gases in the proper place and manner.
6. Raising the temperature of the gases to that required for union and combustion.
7. Effecting their diffusion before they are cooled below the temperature of chemical action.

I conclude, in the words of Doctor Kane, who observes, that, "as these suggestions indicate to the engineer and mechanist the principles on which alone the perfect combustion of fuel can be secured, they serve, also, as an additional proof, (were such wanted,) that complete success in art: the greatest economy in materials: and the most perfect utilization of its products, can only occur when the *scientific conditions* of the process are clearly understood, and made the *foundations* of *practice*."

END OF PART FIRST.

APPENDIX I.

REMARKS ON THE FOREGOING MODE OF EFFECTING THE COMBUSTION OF COAL IN FURNACES.

The following Testimonials, from high chemical authorities, have been selected from a number of others to the same import, and are here given in the order in which they were received and read by the Author, in his Course of Lectures, at the Literary and Scientific Institution, Liverpool.

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REMARKS BY MR. BRANDE.

Royal Mint, London, 26th November, 1840.

My dear Sir,—I am convinced, that you are not only practically, but theoretically and scientifically, right in regard to the general views put forth in your Essay on the Combustion of Coal and the Prevention of Smoke. I have long advocated the principles which you have adopted, and have annually illustrated them in my lectures in the Royal Institution ; but it unfortunately so happens, that, when *scientific* men urge new views, or suggest the practical adoption of rational theories, they are neglected, because it is presumed they are merely founded on unsubstantial hypotheses ; and, on the other hand, when *practical* men attempt to found improvement on scientific principles, they are sneered at as dabblers in science ; and so, both become disheartened and disgusted, and the only people who are temporarily successful are *quacks*, who, pretending to what is called originality, and, neither referring to practice or science, steal from both ; but, deficient in all knowledge of their own, ultimately mislead their followers ; and, like the alchemists of old, not unfrequently deceive themselves.

Under these circumstances, it is really refreshing to find a person of your experience willing and able to blend practice with science and theory ; and I have no hesitation in saying, that the views promulgated in your Essay are substantially founded upon just and scientific principles.

When the unburned hydrocarbons, which are produced during what is commonly called the *combustion*, but which, in reality, is principally the *destructive distillation*, of coal, in our ordinary steam-boiler furnaces, gradually mix with air, they assume the form of what is called uninflammable smoke ; but, if they be examined *immediately after* they leave the fuel and *before* they have blended with excess of cold air in the chimney shaft, they are found to be highly inflammable and rich in carbon. *At this point* it is that you judiciously admit the jets of air ; and in so doing, every jet which enters the inflammable atmosphere within the flues becomes, as it were, the centre of combustion, and tends to increase the heat by burning and destroying that hydrocarbon which otherwise would go on to produce worse than useless smoke.

When air is admitted in front of the furnace, or through, or over the fuel, it obviously never can effect those useful purposes which are, at once, obtained by admitting it in due proportion to the intensely-heated inflammable vapours and gases ; or, in other words, to the products of the distillation of coal, at such temperature that they may take fire in its contact. In this way each jet of air which you admit becomes, as it were, the source or centre of a separate flame ; and the effect is exactly that of so many jets of inflammable or coal gas ignited in the air : only, in your furnace, you invert this ordinary state of things, and use a jet of air thrown into an atmosphere of inflammable gas ; thus making an experiment upon a large and practical, which I have often made on a small and theoretical, scale, in illustration of the inaccuracy of the common terms of "*combustible*" and "*supporter of combustion*", as ordinarily applied.

I fill a bladder with coal-gas, and attach to it a jet, by which I burn a flame of that gas in an atmosphere of, or a bell glass filled with, oxygen : of course, the gas burns brilliantly, and we call the gas the combustible, and the oxygen the supporter of combustion. If I now invert this common order of things, and fill the bladder with oxygen, and the bell glass with coal-gas, I find that the jet of *oxygen* may be inflamed in the atmosphere of *coal-gas* with exactly the same general phenomena as when the jet of *coal-gas* is inflamed in the atmosphere of *oxygen*. This is precisely your process. You admit a number of jets of air into a heated, inflammable atmosphere, and so attain its combustion in such a way as to produce a great increase of heat ; and, as a necessary consequence, destroy the smoke. You, in fact, convert what is commonly called smoke into fuel, at the *time when*, and the *place where*, this combustion can be most effectively brought about.

I have now given you my candid opinion respecting your views of the phenomena of combustion and their application to the object proposed in your Essay : there are some of the minor points of which I cannot speak without further consideration ; but these do not, in any way, affect the main object of the inquiry in its practical bearings.

I am always, my dear Sir, sincerely yours,
WILLIAM THOMAS BRANDE.

To Charles W. Williams, Esq.,
Dublin Steam Company, Liverpool.

REMARKS BY DR. URE.

London, 13, Charlotte-street, 28th Nov., 1840.

My dear Sir,—I have been perusing your treatise "On the Combustion of Coal and the Prevention of Smoke, Chemically and Practically considered," with extreme pleasure, and shall be able, in the course of a few days hence, to write you more particularly my opinion as to the great merits of your invention for obtaining the maximum calorific effect of fuel, and that without the nuisance of smoke. Meanwhile, I shall only state, that I consider your theoretical views to be chemically correct, and their application to steam-boilers to be fraught with the most signal advantages.

I remain, my dear Sir, your very faithful Servant,
ANDREW URE.

To Charles W. Williams, Esq.

obtained a greater quantity of heat from the so-called bituminous species; a result quite in accordance with long established chemical data. The immortal Lavoisier and Laplace ascertained, that one pound of hydrogen, when burned in their celebrated calorimeter, melted 295·6lbs. of ice, while one pound of charcoal melted only 96·5lbs.; quantities very nearly in the ratio of 3 to 1; Despretz gives the ratio of 315 to 104; thus proving beyond a doubt, that hydrogen can disengage, in its combustion, three times more heat than the same weight of charcoal. It deserves to be remarked, that this ratio is exactly the inverse of that in which hydrogen and carbon unite with oxygen; for 1 part of hydrogen, by weight, combines with 8 of oxygen to form water; and 3 parts of carbon combine with 8 of oxygen to form carbonic acid gas, which is the product of the complete combustion of charcoal. From these and similar researches, chemists have been led to conclude, that the heat afforded by different bodies in the act of their combustion is proportional to the quantity of oxygen which they consume; a conclusion which accords, also, with the principle, that the intensity of heat is proportional to the intensity of chemical action, as measured by the proportion of oxygen which enters into combination.

For the first accurate analysis of pit-coals, we are indebted to Mr. Thomas Richardson, of Newcastle,* who published, a few years ago, in the eleventh volume of Erdmann's Journal für Chemie, the results of an excellent series of researches on coals, made in Professor Liebig's laboratory. He used the fused chromate of lead to oxygenate the carbon and hydrogen of the coals, with Liebig's new apparatus; and his results deserve entire confidence. In the earlier analyses of coals, made by Dr. Thomson, myself, and others, the peroxide of copper, which was employed to oxygenate the combustible matter, always left some of the carbon unconsumed, and thus occasioned unavoidable errors.

1. Rich caking coal, from Garesfield, near Newcastle, of sp. grav. 1·280, was found to contain as follows:

Carbon	87·952
Hydrogen	5·239
Azote and oxygen	5·416
Ashes	1·393
	100·

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* An account of these experiments has been since presented, by Mr. Richardson, to the Natural History Society of Newcastle-upon-Tyne, and is printed in their Transactions, vol. ii., p. 401, and in the London and Edinburgh Philos. Magazine, vol. xiii., p. 121, for August, 1838.

2. Caking coal, of excellent quality, from South Hetton, in the county of Durham, of sp. grav. 1·274, afforded,

Carbon	83·274
Hydrogen	5·171
Azote and oxygen	9·036
Ashes	2·519
	100·

3. The parrot coal of Edinburgh afforded,

Carbon	67·597
Hydrogen	5·405
Azote and oxygen	12·432
Ashes	14·566
	100·

100 parts of these several kinds of coal take for perfect combustion (subtracting the oxygen contained in the coal) as follows :

1st.	266·7 parts of oxygen :	giving out heat	as the	number	122·56
2d.	250·2	„	„	„	114·98
3d.	217·6	„	„	„	100·00

The quantity of heat is here presumed to be proportional to the quantity of oxygen consumed. M. Regnault published, in Erdmann's Journal, vol. xiii., p. 69, the following statement of his analysis of coals, which is regarded by Professor Löwig as very correct :*

Newcastle coal, of sp. grav. 1·280, affording a much inflated coke, (quite akin to the Garesfield coal, if not the same,) was found to consist of carbon, 87·95 ; hydrogen, 5·24 ; azote and oxygen, 5·41.

A Lancashire coal, of sp. grav. 1·317, which afforded an inflated coke, was found composed of carbon, 83·75 ; hydrogen, 5·66 ; azote and oxygen, 8·04. The quantity of azote is not given separately by either Mr. Richardson or M. Regnault ; but it is known to be inconsiderable. The deficit to 100 in his analyses represents the amount of ashes per cent. Mr. R. says : " With the present means of analysis at our disposal, it is impossible to determine the true amount," (of azote,) " but the coal cannot contain more than two per cent." In the Edinburgh coal he found, by an experiment made on purpose to determine this point, 0·38 per cent. of azote. This uncertainty introduces a proportional ambiguity into the calculation of the quantity of heat evolved, from the quantity of atmospherical oxygen consumed. The less the proportion of azote, in the above analysis, the greater will be that of the oxygen directly combined with the coals, and the less atmospherical oxygen, of course, will be consumed, which is the only source of the heat disengaged.

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* Chemie der Organischen Verbindungen, vol. ii., p. 88.

Since it is the proportion of hydrogen in coal that determines the proportion of volatile products, a tolerable approximation upon this point is afforded by the proportional loss of weight which different coals suffer from ignition in retorts or covered crucibles. I found that 100 parts of the Felling-main coal used by some of the London Gas Companies, when strongly ignited in a covered crucible, well-luted, lost 37·5 per cent., leaving 62·5 of a porous coke. The Llangennock coals from Caermarthenshire, of sp. grav. 1·337, lose by ignition only 15·5, and leave 84·5 of a rather dense coke, which contains 3 of ashes. In furnaces of the common construction about London, this coal affords much heat with little smoke, and is, therefore, greatly in request, and fetches a high price. 100 parts of the Tanfield Moor coal, of sp. grav. 1·269, preferred by blacksmiths for their forge, on account of its calorific strength and freedom from sulphur, give off in ignition 32·5 parts, and leave 67·5 of a bulky, compact coke.

Every coal which contains much hydrogen, and, therefore, loses much weight by ignition in retorts, necessarily produces much smoke, with a great waste of heat in our common steam-boiler furnaces, for reasons which you have so well developed in your treatise. "When a carburetted hydrogen," says Liebig, "is kindled, and just as much oxygen admitted to it as will consume its hydrogen, the carbon does not burn at all, but is deposited (or separated) in the form of soot; if the quantity of oxygen is not sufficient to burn even all the hydrogen, carburets of hydrogen are produced poorer in hydrogen than the original carburetted hydrogen."* The above gas and smithy coals which, from their richness in hydrogen, are capable of affording the greatest proportion of heat by thorough combustion, afford often a much smaller quantity than the Llangennock, because the carburetted hydrogen which they so abundantly evolve is not supplied with a *due* quantity of oxygen, and hence much of their carbon goes off in smoke, and their subcarburetted hydrogen gas in an invisible form. These results are quite accordant with my experiments on these coals with my calorimeter. At first, from certain defects in the apparatus, whereby the coals were imperfectly burned and a good deal of smoke was disengaged, I found that the best coals imported into London, such as Lambton's Wallsend, Hetton Do. and Pole's Main, afforded a smaller proportion of heat than the Llangennock, or even anthracite; but, when I diminished these defects, I obtained much more heat from the Tanfield Moor coal than from the Llangennock, and more from this than from the anthracite. In fact, a coal which, like the Newcastle caking coal, contains 5·239 of hydrogen, is capable of giving out in complete combustion as much heat as if it contained an extra 10½ per cent. of carbon; but, instead of this additional heat, it affords in common furnaces much less heat than the Llangennock, though this is much poorer in the most calorific constituent, viz., the hydrogen.

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* Traité de Chimie Organique, Introduction, p. 32.

It is a remarkable fact, that an inflammable constituent of pit-coal, which is always present, and often invisibly combined with it to the amount of 5 per cent. or more, has never been noticed in any of the ultimate analyses hitherto published. I have examined a great variety of coals from different parts of the world, and I have seldom found less than 2 per cent. of sulphur in them. Now, this is a circumstance of great consequence to many manufacturers, and most essentially to ironmasters. Some of my results upon this subject were published in the number of the *Athenæum* above quoted. Sulphur in its calorific power ranks low, being, according to Dr. Dalton, one-half of carbon. If we assume its consumption of oxygen in combustion as the measure of its heating power, it will stand to carbon in the relation of 3 to 8; for 3 parts of carbon consume 8 of oxygen to form carbonic acid, while 8 of sulphur consume 8 of oxygen when they are burned into sulphurous acid. The blacksmith knows well what havoc a sulphurous coal makes among his iron in the forge, rendering it entirely *rotten*. The same operation takes place upon the rivets and plates of steam-boilers, when the sulphur of the coals is merely volatilized, without being mingled with sufficient air to burn it.

The first operation which coals undergo, on being heaved into a common furnace, is distillation, attended with a great absorption of heat, and may be compared to the distillation of sulphur in the process of refining it, for which purpose much external heat is required. But, if the fumes of sulphur or the coals be, after accension, intermingled with the due quantity of atmospherical oxygen, they will, on the contrary, generate internally, from the beginning, their respective calorific effects.

At the outset of my chemical career, I suffered in a painful and dangerous way from the refrigeration produced by throwing some pit-coal into a hot furnace. I was extracting oxygen, for common class experiments, from nitre ignited in a large iron bottle, when, having replenished the fire with coal, the gas became condensed in the bottle so much as to occasion a regurgitation of water into it from the gasometer basin, which water, being instantly converted into high-pressure steam, drove out a quantity of red-hot nitre upon my shoulder and arm, so as to burn not only my clothes, but a very considerable portion of my skin. In an experimental furnace, so treated, the heat is greatly damped as long as the hydrogenated vapours and gases are being generated ; and it becomes again effective only when the coals have become nearly charred. Were there a contrivance like your patent invention introduced into the furnace for diffusing atmospherical oxygen through the said vapours and gases, no vexatious refrigeration could ensue from feeding the fire, prudently, with common pit-coal ; and the external orifice through which this smoke-burning air was admitted might be closed whenever the fire became clear.

In the case of great steam-boiler furnaces, for which your patent is especially intended, since these are fed at short intervals, your plan of distributing atmospheric air, in a regulated quantity, by numerous jets, through the body of the gasiform matter, is peculiarly happy, and must enable you to extract the whole heat which the combustible is capable of affording. The method also which you have contrived for distributing the air under the surface of the grate will ensure due combustion of the coked coals lying there, without admitting a refrigerating blast to the fire. And, finally, your mode of supplying atmospherical oxygen will prevent the possibility of the carbon of the coals escaping in the state of carbonic oxide gas, whereby, at present, much heat is lost in our great furnaces.

ANDREW URE.

13, Charlotte-street, Bedford-square, London,
December 26, 1840.

FURTHER REMARKS BY DR. BRETT.

Laboratory, Royal Institution, Liverpool, Jan. 6, 1841.

I now take the opportunity of expressing more fully my opinion of your views concerning the combustion of coal and prevention of smoke, and it gives me the greater satisfaction so to do, in consequence of having enjoyed, on more than one occasion, an opportunity of examining, in your experimental furnace, when in operation, the different stages of coal combustion. Your furnace being so constructed that it allows of a close inspection of the changes which take place within the flue behind the bridge, no person, however imperfectly acquainted with those scientific principles upon which combustion ought to be effected, can avoid recognising the great difference (a difference sufficiently palpable to the sight) which exists between combustion, as conducted in furnaces upon the old plan, and that which takes place in yours, when the inflammable matters receive *good air properly supplied.*

The importance of this supply of good, instead of vitiated, air, *at a proper time and place*, and the no less important influence which a thorough *commingling* of the substances to be burnt and the substance burning exerts in facilitating full and complete chemical union, has been satisfactorily shown in your treatise; and the injurious effects from a neglect of these precautions no less clearly demonstrated; and this appears to be quite manifest, if we look to the nature of the elementary substances which enter into the composition of all ordinary pit-coal.

These elements, exclusive of earthy, saline, or metallic compounds, are, carbon, hydrogen, oxygen, nitrogen, and, not unfrequently, sulphur. The carbon, hydrogen, and sulphur may be regarded as the combustible elements, but they differ materially as regards the amount of heat which they respectively evolve, when burnt, in equal weights, with oxygen; the first place belonging to hydrogen and the last to sulphur: hence the great value of highly-hydrogenated coal for certain calorific purposes.

If coal be submitted to heat in large vessels, as in the coal-gas retorts, combustion does not take place, but the elements pre-existing in the coal undergo new arrangements, giving birth to volatile substances, which pass off, leaving behind a solid carbonaceous matter, or coke. These gaseous or volatile substances are sufficiently numerous, consisting of light and heavy hydro-carbons, napthaline, sulphuretted hydrogen, carbonic oxide, ammonia, cyanogen, free hydrogen, and sulphuret of carbon; all these compounds being produced from the five already-mentioned elementary bodies. A portion of the heavy hydro-carbon, or olefiant gas, suffers decomposition at the high temperatures of the gas retorts, carbon being deposited in no inconsiderable quantities even upon the roof of these retorts, light carburetted hydrogen passing off as gas.

This, then, appears to be the state of things which obtains when coal is submitted to destructive distillation without aërial contact. When, however, coal is submitted to the agency of heat, for special calorific purposes, *with* aërial contact, then actual combustion ensues, either partial or complete, according to the *manner* in which atmospheric air is supplied; the great object always being to prevent the formation, or, at all events, the permanent existence, of those compounds, especially the nitrogenous ones already enumerated; instead of which, the only products ought to be carbonic acid and water, with some nitrogen, and, occasionally, a small quantity of sulphurous acid. The old mode of combustion in furnaces is manifestly incompetent to effect this perfect combustion, and only to be attained, in my opinion, by a plan based upon such principles as you have advocated.

Every one who observes the volumes of black smoke escaping from the chimneys of manufactories must be struck with the positive loss of fuel thus sustained; yet, not only is the black smoke lost for calorific effect, but a further loss may be traced to the passing off of what may be called a smoke, though not visible—I mean unburnt carburetted hydrogen and carbonic oxide. You have been fully alive to the truth of this; and, by a felicitous contrivance, have shown, that, by mingling atmospheric air with the inflammable gas, before they can escape unburnt, black smoke may be got rid of, or, in other words, that loss of fuel and consequent loss of heat may be avoided.

On one occasion, whilst watching the process of combustion, during its different stages, in your experimental furnace, at that period when the hydro-carbons had just undergone combustion, and the carbonaceous matter, or coke, was remaining on the fire-bars, highly ignited, I observed, when looking into the flue, the phenomenon of a peach-coloured flame mingled with one of a striking blue colour. The former I believe to have been produced by the burning of cyanogen: the latter was undoubtedly due to carbonic oxide. To the interesting fact of the combustion of the latter gas, after that of the hydro-carbons, you will remember to have directed my attention on a former occasion. I need hardly say, that, without a proper supply of atmospheric air, these gases would have escaped by the chimney, and so have been lost for calorific purposes.

I will conclude these observations by a remark or two on a point much insisted upon in your treatise, as it appears to me of great importance, namely, the *diffusion* of the atmospheric air and inflammable gases as much as possible into each other, *prior* to combustion. In doing this, you but follow out the rule which science and experience alike dictate, which is, to cause as intimate a mixture as possible of those substances between which you desire that chemical union should take place. Combustion is a phenomenon attending chemical union, and the previous mechanical arrangement of the bodies to be united should be, and are, in your plan, carefully observed.

By causing atmospheric air to be driven, *by jets*, among the inflammable gases, you employ, as it appears to me, the only means practicable, in operations on a large scale, of causing a sufficient mechanical admixture between the air and the gases to be burnt. By such means, too, you considerably extend the surface of any given bulk of atmospheric air admitted, in the same way as the surface of any given volume of water is greatly increased by causing it to pass, in thin streams, through a vessel containing numerous apertures.

The importance of a due supply of atmospheric air to coal-gas, and a proper admixture of the one among the other, prior to combustion, may be shown by taking a piece of wire gauze, placing it nearly in contact with the perforations of a common gas argand-burner, and then turning on the gas and inflaming it. After it has passed the wire gauze, the flame will be found to be luminous and fuliginous, and a piece of platinum wire placed across it will be only heated to dull redness about the external part of the flame; but if, whilst things are in this condition, the wire gauze be raised so as to leave a space of some few inches between the orifices of the burner and the under surface of the gauze, the flame speedily loses its luminous properties to a great extent, is no longer fuliginous, and has so increased its calorific properties as to cause the platinum wire to be heated to bright redness.

In the first experiment, imperfect combustion takes place, from an inadequate supply of atmospheric air and want of diffusion of the air and coal-gas among each other. Hence the luminosity of the flame, containing, as it does, solid unburnt carbon, and hence, also, its less powerful heating properties and fuliginous character. In the latter experiment, the air becomes mingled with the coal-gas before passing through the wire gauze; and, when this mixture is inflamed *above* the gauze, perfect combustion takes place, no smoke is produced, and a great increase of heat obtained.

On the whole, then, I would observe, that your treatise is correct as to its theoretical and scientific principles; and, by your illustrations on the large scale of the furnace, you have demonstrated how science and practice may be made to harmonize, and have shown the importance of attending, strictly, to the *chemical* conditions on which combustion takes place, without which all must be error and uncertainty.

R. H. BRETT, Ph. D., F.L.S.

To C. W. Williams, Esq.

REMARKS BY DR. ROBERT KANE.

Royal Dublin Society, January 16th, 1841.

Dear Sir,—I received the copy of your work and the other papers illustrative of your views of the nature of combustion and of the construction of furnaces, and I consider your suggestions as being of peculiar value, inasmuch as they indicate to the engineer and mechanist the principles on which alone the perfect combustion of fuel can be secured. They serve also as an additional proof, were such wanted, that complete success in art—the greatest economy in materials—and the most perfect utilization of its products can only occur when the *scientific* conditions of the process are clearly understood and made the *foundations of practice.*

In your furnace alone, of all the plans I have had an opportunity of examining, the conditions for the complete combustion of *all* the constitients of the fuel are secured in the proper circumstances of *quantity, time,* and *place.*

The introduction of air at the bridge and along the flame-bed, to supply the quantity of oxygen necessary for the combustion of the volatile products of the coal;—the diffusion of this air, secured by its issuing from a great number of small jets, and the consequent full combustion of the gaseous fuel before it leaves the surface of contact with the boiler, are elements of real economy and success in practice. The value of this, although, perhaps, obscurely felt by others, from the imperfection of the older methods, has been certainly first placed in its important and just aspect by your illustrations.

The formation of *carbonic oxide* in furnaces, to which I find, in your work, for the first time, the attention of practical men directed, has, hitherto, been a source of loss of fuel to a very considerable extent. When carbonic *acid* streams over a surface of ignited charcoal, or coke, it cannot be considered to evolve heat in taking up an additional equivalent of carbon. This is verified by the fact, that the carbonic oxide thus formed gives out, in burning, only the same quantity of heat which the second equivalent of carbon should have given out if it had formed *carbonic acid directly.*

This heat you encourge, and hence, even at those periods when carbonic oxide is produced, you lose no fuel, whereas, in all the ordinary plans of avoiding *visible smoke,* the fuel is evolve in carbonic oxide, and is either silently escaping as *invisible* gas or burns at the orifice of the chimney, wasting there the carbon which should have been economized below.

I like the plan of your diagrams very much. In popular use, and, especially, for the instruction of those who have not made abstract calculations their study, they are exceedingly valuable : so much so that our illustrious and venerable friend, Dr. Dalton, the Nestor of the physical sciences, as he has been termed by Dumas, proposed a plan not unlike yours, but which, from the very fact of its being more adapted to class illustrations than to the calculations by symbols, (now so necessary in scientific chemistry,) was kept very much out of view, lately, by the employment of the Berzelian notation. I am glad, therefore, that you propose colouring these diagrams in a second edition; for, when one writes, as you do, not merely for those who know a good deal, but for those who are not used to the kinds of ideas you wish to communicate, every adjunct which tends to awaken the senses to the subject is of the highest importance.

In conclusion, I beg to express my conviction, that, by giving to the scientific world the true philosophy of combustion upon the large scale of the furnace, and indicating to the mechanist the conditions upon which the proper construction of furnaces must rest, you have illustrated, remarkably, the value of science applied to the useful arts, and have effected considerable service to the public.

Believe me, my dear Sir,
Sincerely yours,
ROBERT KANE.

To C. W. Williams, Esq.

APPENDIX II.

WHILE these pages were passing through the press, the Monthly Minutes of the Institution of Civil Engineers have been issued. At page 62 I find a copious abstract of a paper read to the Institution, "On the Properties and Chemical Constituents of Coal," by Charles Hood, F.R.A.S.

I here insert this paper as it contains much interesting matter touching the subject of the preceding observations; and as it corroborates, in many respects, what I have been urging. As, however, it contains several serious chemical errors on the subject of the combustion of the gases, I had prepared some observations in reply: but, having taken the opinion of a very competent authority, Dr. Robert Kane, of the Royal Dublin Society, I have given that Professor's opinion and observations in preference to my own.

I cannot here avoid expressing my surprise, that Mr. Hood should have overlooked the chemical inconsistency of supposing, that the ignition and combustion of the hydrocarbon gases were, in any way, connected with the bringing them into contiguity with the " mass of incandescent fuel", or that this could lead to economy of fuel or the "combustion of smoke." Dr. Kane's observations are conclusive on this head.

"ON THE PROPERTIES AND CHEMICAL CONSTITUTION OF COAL, WITH REMARKS ON THE METHODS OF INCREASING ITS CALORIFIC EFFECT AND PREVENTING THE LOSS WHICH OCCURS DURING ITS COMBUSTION. BY CHARLES HOOD, F.R.A.S., &c."—*Extracted from the Transactions of the Institution of Civil Engineers.*

The author considers his subject under three heads:—First, the chemical character and composition of coal; secondly, its properties as a combustible; and, thirdly, the nature and application of its various gaseous products.

1st. The opinion, that coal is a compound of carbon and bitumen, has been objected to by some chemists, on the ground, that, by no process hitherto pursued in analysis, has it been possible to resolve it *entirely* into these two substances. Even at a low temperature, a quantity of gaseous matter is thrown off; and, at an elevated degree of heat, an evident decomposition of the bitumen takes place. Even anthracite contains a small portion of volatile matter, its component parts being carbon, oxygen, hydrogen, and nitrogen; the hydrogen being either combined with the oxygen, to form water, or with a small portion of carbon, to form carburetted hydrogen, which exists, in a gaseous state, in the pores of the coal. In bituminous coal, the hydrogen is combined with a larger proportion of oxygen and nitrogen, the mechanical difference being, that the bituminous and free-burning coals (more particularly) melt by heat when the bitumen reaches the boiling point, whereas anthracite is not fusible, nor will it change its form, until it is exposed to a much higher degree of temperature.

Two tables of the analyses of different coals are given from the authorities of Mushet, Thomson, Vanuxem, Daniells, Ure, and Reynault. No. 1 showing the proportions of carbon, ashes, and volatile matter, with the specific gravity of the coal and of the coke; and No. 2 showing the proportions of carbon, hydrogen, azote, and oxygen. These tables show, that the largest quantity of carbon (92·87) is contained in the Kilkenny anthracite, and the least quantity (64·72) in cannel coal; and that the nature of the volatile matter greatly affects the quantity of coke—the aggregate quantity of the gaseous products of coking, splint, and cherry coal being very nearly similar; while the quantity of coke obtained from these different species varies more than 45 per cent.

The author then points out the continual presence of azote, which quits the base with the greatest difficulty; and also the affinity of sulphur, not only for the coal, but for the coke, as it is rarely found to have been completely expelled even from the most perfectly made coke; the only coal found to be even partially free from it being anthracite, in some species of which no traces of its presence are found.

2dly. The application of coal as fuel depends on the chemical change which it undergoes in uniting by the agency of heat with some body for which it possesses a powerful affinity. In all ordinary cases this effect is produced by its union with oxygen. When coal is entirely consumed, the carbon is wholly converted into carbonic acid gas and carbonic oxide, and the hydrogen into water in a state of vapour. The atmosphere supplies the necessary oxygen for this purpose; and in this state the products of the combination are nearly or quite invisible, both of them being almost colourless fluids: if, therefore, any smoke be visible, it is the result of imperfect combustion. Some calculations are given to ascertain the amount of loss that is sustained when the smoke escapes unconsumed; from which it appears, that with bituminous coal about 37 or 38 per cent. more heat is produced when the smoke is consumed than when it escapes freely.

Many modes of consuming smoke have been attempted: those which appear to have been attended with the greatest success are, —1st, Causing the smoke from the fresh coals to pass *through* or *over* that portion of the fuel which is more perfectly ignited; 2dly, Supplying *heated air* to the top of the fuel, as well as admitting cold air through the ashpit in the usual manner; and, 3dly, Throwing a *jet of steam* into the furnace or into the chimney. The various modes of carrying into effect these plans are briefly alluded to: from them a few may be selected. Robertson's plan was to use inclined furnace bars, where the fresh coals were placed close to the fire-door, and, being there partially carbonized, gave out the gas which, in passing *over the mass of incandescent fuel, was ignited,* and became active flame, thus *economizing fuel* and *preventing smoke.* In this and similar cases, by the slow distillation of the coal, a gas is produced, which not only inflames at a *lower temperature* than the dense *olefiant* gas produced by rapid distillation, but which only requires for its combustion a quantity of oxygen, never exceeding double its own volume, or ten times its bulk of atmospheric air, while olefiant gas requires three times its own volume of oxygen, or fifteen times its bulk of atmospheric air. The elimination of a gas which burns with *so small a portion of oxygen* is, therefore, the principal cause of the non-production of smoke in furnaces of this description.

The second mode of consuming smoke is founded on the necessity which exists for a large supply of air being requisite to inflame the gases given off from coal by a rapid and intense heat; and this is accomplished by introducing a quantity of heated air above the burning fuel. When a quantity of fuel is thrown into a furnace, the increased thickness of the mass opposes additional resistance to the passage of air through the bars; the temperature of the furnace is lowered, and an increased volume of gas is, at the same time, given out. If, at this moment, a quantity of air, heated to the temperature of the gas, be admitted, the gas immediately inflames, and that which would have produced a dense black smoke passes off in the invisible state of carbonic acid gas and vapour of water. Different gases require different degrees of heat to inflame them; and this explains the *easy combustibility* of the volatile products of coal when the heat is so managed as to produce those gases which inflame at the *lowest* temperature. A larger quantity of air is required at the time that the coal is first thrown on than at a subsequent period; therefore, when economy is studied, the supply of air should be gradually diminished as the mass approaches an incandescent state. The use of heated air has produced most important results in the manufacture of iron with bituminous coal, and also with anthracite; the latter fuel having been almost neglected until the recent application of this principle of employing heated air to promote its combustion, although it is known to be capable of producing, perhaps, a more intense heat than any other carbonaceous fuel.

The rationale of the third plan of consuming smoke, by injecting a jet of steam into the fire or the chimney, is less obvious than the others. In 1805 Mr. Davies Gilbert observed, that whenever the waste steam of one of Mr. Trevithick's engines was permitted to escape into the chimney, the smoke from the coal was rendered *invisible*. Subsequent experiments confirmed this fact; and it was supposed, that the steam, being decomposed, furnished oxygen to support combustion. The author combats this opinion, and accounts for the effect by the increased draught of the furnace caused by the jet of steam into the chimney, by which means a larger portion of air is brought into contact with the burning fuel; thus supplying the previous deficiency of oxygen to the fire, and promoting the combustion. As steam is only about half the weight of air at a like temperature, and the power of all gaseous fluids to ascend is "*inversely* as the square roots of their specific gravities", the velocity of its escape by the chimney, compared with common air of the same temperature, is about as 1·4 to 1 ; therefore, the *compound mixture of steam, air, and carbonic acid gas will escape with a considerably increased velocity*, and more air must, consequently, enter the furnace. It appears, that about ten per cent. of the total quantity of steam generated is necessary to effect the combustion of the smoke by this means ; therefore, unless the waste steam only be used, the saving of the fuel must be reduced by this amount.

Brief mention is made of the experiments of Messrs. Apsley, Pellatt, Parkes, and the Chevalier de Pambour, proving that a given quantity of oven coke will preduce as much heat as the coal from which it was produced ; and of the various kinds of artificial fuels which have been invented, especially that composed of *resin* and *peat coke*, of which the author remarks, that its combustion probably produces a mechanical effect, as the hydrogen is converted into water in a state of vapour, which escapes through the chimney with a great velocity, and, consequently, a large quantity of air is drawn into the furnace, and a more perfect combustion of the fuel is the result. In the same manner he accounts for the necessity which exists for having the openings between the bars wider in a furnace in which coke is burned than in one used for coal. In opposition to the general opinion, he considers that less air is required for the consumption of coke than for coal ; the carbon only requiring 2⅓ times its weight of oxygen for its combustion, while the hydrogen contained in coal requires 8 times its weight of oxygen : and the only reason that the openings between the bars are required to be wider in the former than in the latter case, is in consequence of the draught being so much slower during the combustion of coke.

3dly. "On the nature and application of the volatile products of coal." In treating this portion of the subject, many of the observations on which have been necessarily anticipated in the preceding sections, the author traces the application of carburetted hydrogen gas to the purposes of artificial illumination from the year 1798, when its first successful application was made by Murdock, at Soho : he then proceeds to Dr. Henry's investigations of the phenomena of its production and combustion ; the variation of the intensity of light obtained from carburetted hydrogen, due to the proportion of carbon contained in it ; the difference in the gas obtained from different qualities of coal ; the superiority of the illuminating power of the gas from cannel coal ; and the still greater power of that produced from the decomposition of oil, which is two to two and a-half times greater than that of coal-gas. He then mentions the other products of coal by distillation, such as ammoniacal liquor, carbonic acid and oxide, sulphuretted hydrogen, tar, essential oil, naptha, petroleum, asphaltum, and other substances. The paper concludes by pointing out the advantages which would result from the production of such gas as is usually given out at the beginning of the distillation of coal, as it contains two volumes of gaseous carbon united with two volumes of hydrogen, and its illuminating power is, consequently, more than double that of ordinary coal-gas.

DR. KANE'S OBSERVATIONS ON THE ABOVE.

Laboratory of the Apothecaries' Hall, Dublin,
Sept. 4, 1840.

In reply to your inquiries respecting the details in Mr. Hood's paper, presented to the Institution of Civil Engineers, I have to observe, that there are several inconsistencies in it, a few of which I will point out. First, the light carburetted hydrogen is not among the *first* products of the distillation of coal; but is formed, on the contrary, only when the volatile resin-oils and the olefiant gas (which are, in reality, the first products) are decomposed by sweeping over the ignited surface of coal, or metal of the retort, or its contents.

When olefiant gas is passed through tubes heated to bright redness it deposits half its carbon, and, without changing its volume, is converted into light carburetted hydrogen. If it be frequently passed backward and forward through the tube, it deposits *all* its carbon, and the residual gas (the volume of which is *doubled*) is found to be pure hydrogen.

The products of the distillation of coal may be arranged according to the temperature at which they may be produced, as follows:

1st. Lowest temperature,	Solids, as napthaline, solid resins, and fluids with high boiling points.
2d, or next temperature,	Fluids which are very volatile.
3d stage,	Olefiant gas.
4th stage,	Light carburetted hydrogen gas.
5th, or highest temperature,	Hydrogen gas.

In practice, however, the results of two or three stages are always mixed together.

2d. Light carburetted hydrogen is *more difficult* to inflame than olefiant gas (Mr. Hood's paper states the reverse.) Davy has fully proved this;

and I have verified his result, that a mixture of air and olefiant gas will explode at a temperature that will not produce action on a mixture of air and light carburetted hydrogen.

3d. The heat produced by olefiant gas, in burning, is greater than that produced by the combustion of the *same volume* of light carburetted hydrogen in the proportion of 27 to 18. The weights are then, however, as their specific gravities; that is, as 98 is to 56. If we plunge a piece of bright *red* charcoal, or a bright *red* iron rod, into a mixture of olefiant gas and air, it will explode; but we may immerse the charcoal and iron, *white* hot, into a mixture of light carburetted hydrogen without any danger. The whole use of the safety lamp depends on this.

4th. Mr. Hood is quite in error respecting the source of the ascentional power of gas and its law. It has nothing to do with the law of *tranquil diffusion* into space, with which he has confounded it.

5th. He is also wrong respecting the source of the great heating powers of the resin fuel. The idea of an increased draught from the quantity of *vapour formed* is also quite incorrect.

6th. There is nothing gained by the production of a gas requiring less oxygen (as Mr. Hood supposes) than olefiant gas does, for there would then be less heat produced. The quantity of heat evolved in the burning of any body is proportional to the quantity of oxygen absorbed, and it is hence the interest of the operator to use as *much oxygen as possible*, instead of the reverse. With regard to the law of the quantity of heat evolved being proportioned to the quantity of oxygen consumed, the following extract, from the article "Combustion", in my "Elements of Chemistry", (now in the press,) will be sufficient to explain it.

" The determination of the quantity of heat produced during the combustion of a given quantity of a combustible substance is a problem of great importance in the arts, as on it depends the economic value of all varieties of fuel. The plan generally followed has been to burn the substance, by means of the smallest quantity of air which is sufficient, in a vessel surrounded, as far as possible, with water.

" If it be found, that the burning *a pound of wood* heats 37 pounds of water from 32° to 212°, no idea can be thereby formed of the quantity of heat evolved. But if, in another trial, it be found, that the burning of *a pound of charcoal* raises the temperature of 74 pounds of water through the same range, it follows, that the *charcoal* has double the calorific power of the *wood*. True *relative* numbers can thus be obtained, although they have, independently, no positive signification.

" The results obtained in this way, by various experimentors, have been exceedingly discordant; but, by the the late researches of Despretz and of Bull, a very interesting rule has been obtained. It is, that in all cases of combustion the quantity of heat evolved is proportional to the quantity of oxygen which enters into combination.

" Thus Despretz found that there are heated from 32° to 212° by

1 ℔. of oxygen, uniting with hydrogen, 29½ ℔s. of water.
1 " " " charcoal, 29 " "
1 " " " alcohol, 28 " "
1 " " " ether, 28½ " "

giving, as a mean, 28¾ ℔s. as the quantity of water heated from 32° to 212° by the heat evolved in the combination of one pound of oxygen.

" This rule, however, is liable to some very curious changes," &c. &c.

ROBERT KANE.

To C. W. Williams, Esq., Liverpool.

APPENDIX III.

EXTRACTS FROM THE SPECIFICATION OF THE AUTHOR'S PATENT FURNACE, FOR EFFECTING THE COMBUSTION OF COALS ON TRUE CHEMICAL PRINCIPLES, AS REVISED BY DR. URE.

"That the above arrangements for producing the greatest calorific effect may be better understood, I add the following observations:

"Hitherto, in the construction of furnaces, due attention has not been paid to the chemical conditions of the formation of smoke, and the important distinction which exists between the *volatile* and the *fixed* constituents of coal,—the circumstances under which they give out heat,—and the peculiarities of their respective modes of combustion.

"Smoke is the result of the *imperfect combustion* of the volatile products, in consequence of their being mixed with either too small or too large a proportion of atmospheric air. Either of these circumstances, that is, too little air with a high, or too much air with a low, temperature, causes the separation of the carbon from the hydrogen, and the consequent change of the carbon, from the colourless state of gaseous combination, into a black, palpable, and pulverulent form.

"The carburetted hydrogen gases require, as the condition of their combustion, *first*, that they be *intimately blended* with an appropriate volume of atmospheric air (which volume varies with the nature of the combustible gas); and, *secondly*, that, *after* having been so mixed with the air, *the mixture be heated to the temperature* of accension, or be brought in contact with flame.

"Again, as one cubic foot of carburetted hydrogen gas requires *two* cubic feet of oxygen, or *ten* cubic feet of atmospheric air; while one cubic foot of bi-carburetted hydrogen, or olefiant gas, requires *three* cubic feet of oxygen, or *fifteen* of air, to effect complete combustion; these proportional volumes of air must be supplied, and so *intimately blended as to bring the particles of the combustible gases and atmospheric air within the sphere of their reciprocal and chemical attraction;* for, otherwise, the inflammable gases will not be completely saturated with oxygen, that is, *will not be consumed;* and, consequently, the full calorific effect of the body of gas generated from the coals will not be obtained.

"Now, in ordinary furnaces, as generally constructed, the air cannot reach the body of gas that escapes from the fire-place into the flues, *except by passing through the highly ignited fuel laid upon the bars of the grate,* whereby much of its oxygen gets saturated, inert, and incapable of consuming or burning the residuary combustible gases and fuliginous vapours, to whatever intensity of heat the æriform mixture be subjected.

"The unignited gaseous mixture, in travelling through the flues, loses temperature very fast, and deposits the eliminated carbon in the form of sooty smoke: thus, not only much of the *carbon,* but a good deal of the *hydrogen,* with which it was previously combined, are lost to the furnace for the purposes of ignition; while some of the hydrogen, uniting with the nitrogen, forms ammonia, a gas which, by its presence, is eminently obstructive of the high temperature of flame.

"It will now be seen, that the construction of this furnace, and the principles on which it is based, are strictly in conformity with the complex and purely chemical processes going on in the furnace, supplying each process with the means necessary to its completion, and *in their proper order,* viz.,

"1. The generation of the combustible gas from each charge of *fresh* fuel, by the radiant heat resulting from the *preceding* charges then in a state of incandescence.

"2. The supplying such gas with the quantity of oxygen necessary to their most perfect chemical union and combustion, and in a manner more favourable to their instantaneous and complete intermixture.

"3. The effecting this incorporation of the gas and the atmospheric air, not only in the proper quantity but at the proper time, that is, *before* the mixture has passed into the flues beyond the influence of the high temperature essential to ignition.

"4. The supplying this atmospheric air from a source independent of the currents in the ashpit, thus preventing its coming in contact with the incandescent carbonaceous fuel on the bars, which would, in such case, have deteriorated it by saturating much of its oxygen.

"5. The separating the two distinct portions of air respectively required for the *volatile* and the *fixed* portions of the coal, and effectually preventing any interference of the one with the other, which might have disturbed or injuriously affected the operation of either.

"Having described the nature of my invention, I do not claim the introduction of air to the bridge, which has already been done by others, but I specially claim, as my invention,

"1. The use, construction, and application of the *perforated air-distributors*, by which the atmospheric air is more immediately and intimately blended with the combustible gases generated in the furnace.

"2. The application of distinct pipes or tubes by which the air is conducted to the gases at the bridge and flame-bed, *in whatever situation they may be placed*, where such pipes or tubes are the means of bringing such air to the gas *independently of the air in the ashpit.*

"3. The use and application of separate perforated tubes, *situated in the ashpit*, as the means of distributing uniformly and along the underside of the bars the air which is intended to be applied to the ignited fuel on them."

Liverpool: T. Bean, Printer, 21, Castle-street.

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